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SS MANHATTEN in Viscount Melville Sound, September 8, 1969

MARITIME SERVICES TO SUPPORT POLAR RESOURCE DEVELOPMENT

Prepared by the

COMMITTEE ON MARITIME SERVICES TO SUPPORT
POLAR RESOURCE DEVELOPMENT

of the

MARITIME TRANSPORTATION RESEARCH BOARD
Commission on Sociotechnical Systems
National Research Council

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This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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Inquiries concerning this publication should be addressed to:

Maritime Transportation Research Board
National Research Council
2101 Constitution Avenue, N.W.
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FOREWORD

This report addresses the maritime requirements and potential for servicing resource development in the polar areas. The study was done under the auspices of the Maritime Transportation Research Board (MTRB) of the National Research Council as part of a continuing program of advisory services to the federal government directed toward improving waterborne transportation systems of the United States.

The study originated from a suggestion by the Maritime Administration that the maritime future of the Arctic regions was one of the basic issues that the MTRB should examine. A study concept was developed by Board member Phillip Eisenberg.

Concurrently, the Marine Board of the National Research Council was planning a study to assess polar ocean technology. To avoid duplication of effort, the MTRB arranged for two Board members, Austin Brant and Thomas Crowley, to participate in the Marine Board study, with the expectation that the MTRB study would follow on to identify the marine transportation requirements and opportunities for polar resource development in greater depth than was possible in the Marine Board study.

Following the final workshop of the Marine Board Panel, the Committee on Maritime Services to Support Polar Resource Development was formed within the MTRB, under the Chairmanship of Professor Donn K. Haglund, to complete the remaining tasks of the study.

A three man review committee has reviewed the report on behalf of the Board and has approved it for publication.

My thanks and those of the Board members go to the committee chairman and members and to the liaison representatives for a job well done. Our thanks also go to the review committee for its efforts on behalf of the Board.

RRONeill
R. R. O'Neill
Chairman
Maritime Transportation Research Board

PREFACE

The present study represents the collective thinking of the Committee on Maritime Transportation to Support Polar Resource Development. Its members have generously contributed their time and their expertise, without compensation. Over a period of more than a year they have assembled in Washington, D.C., from places as dispersed as Churchill, Houston, Seattle, and Boston, on several occasions, to perform most ably the mission for which the committee was formed.

It falls, however, upon a chairman to take final responsibility. With such a distinguished and knowledgeable group of colleagues as I found in this endeavor it is an honor, not a task, to do so. My heart-felt thanks to all.

Donn K. Haglund

Donn K. Haglund
Chairman
Committee on Maritime Services
to Support Polar Development

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Liaison Representatives

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S. B. NEMIROW, Assistant Secretary of Commerce for Maritime Affairs, Maritime Administration

INTRODUCTION

Recent years have seen the United States and other developed nations looking farther and farther afield for sources of essential commodities. The polar regions of the earth are among the planet's major remaining resource frontiers. The Antarctic and especially the Arctic realms have attracted scientific and resource investigators at an accelerating rate. Since World War II there has also been a military interest in the Arctic. The need for transport services in these remote regions has expanded with increasing interest in the far north and far south.

Among the three polar interest communities, scientific, military, and resource development, the present study addresses itself solely to the latter. It is assumed that the military services will continue to assess their own requirements and that they are not likely to generate a demand for substantial increases in transportation services except in an emergency. Similarly, transportation requirements of basic scientific investigation are not expected to extend beyond research vessels nor commercial-military aircraft use.

That there will be a significant increase in demand for transportation services in polar resource development is demonstrated by present events and those of the recent past. Although seekers of furs, fish, sea mammals, and precious metals have extracted wealth from the polar lands and seas for centuries, it was not until the 1960's that concerted efforts were made to develop such industries as petroleum and natural gas extraction on the polar frontier. The developed world, especially the United States, was formerly able to rely on domestic or more readily accessible foreign sources for such basic commodities. Production of the first Arctic coastal Alaskan oil and construction of an elaborate transport system, especially the Trans-Alaska Pipe Line System (TAPS), to deliver its product to market is a prime example of things to come.

While there are both actual and potential roles for various transport modes in polar resource development, the contribution that maritime services can make forms the basis of the present study.

While the twenty-first century may see major resource development activity in both the North and South Polar Regions, it is the judgment of this Committee that such efforts will be limited to the Arctic during the final two decades of this century, the time period to which this study is limited (See Appendix A for discussion of Antarctic Maritime Service Requirements). Continuing and potential marine transportation needs for the Antarctic region are to support scientific research with only limited potential need, in the long run, for tourism and commercial development of living and mineral resources.

Except for the Weddell Sea, Antarctic ice is one year ice. The Arctic presents much more severe ice conditions, therefore transportation technologies for the Southern Ocean will be similar to those required for Arctic waters because of the presence of pack ice and icebergs.

The most important near term Antarctic marine transportation requirement for the U.S. is for a scientific research vessel.

The basic emphasis of the present study therefore is on the Arctic. It is concerned with the special role of maritime transportation, both inbound and outbound, and it includes its ancillary facilities requirements in the movement of extractive resources of the far north. In order to assess this role it is necessary to describe the physical environment (Appendix B) in which this transport will take place and then proceed to the technical considerations that the severities of the Circumpolar North impose upon maritime transportation systems.

Definition

The Arctic is defined in a variety of ways, depending largely on the discipline, audience, or user addressed. To botanists or geologists it may be the area north of the tree line or where permafrost occurs near mean sea level; to cartographers it may be the area north of the Arctic Circle; to climatologists it may be where the average for the warmest month is 10° C or 50° F. But to the marine community, and for our purposes here, it is that region where bordering seas usually have a sea ice cover for some part of the year or season. This may be mostly winter ice cover, i.e., the ice cover may retreat or melt completely for a significant part of the year (navigation season) as in the seas of the northern sea route of the Eurasian Arctic, the Bering Sea, the Chukchi Sea, the near shore areas of the Beaufort Sea, Baffin Bay, the Labrador Sea, the southern East Greenland Sea and the Barents Sea. On the other hand, in some areas such as seaward of the North Alaskan Slope (Beaufort Sea), in regions within the Canadian Archipelago north of the Parry Channel (the classical Northwest Passage), off the northern coasts of Greenland, and the broad, deep expanses of the central Arctic Ocean itself the sea ice cover is perennial. In these areas, ice cover is usually from three-quarters to complete cover, even in the warmest month of the year. It is this deep ocean area, with its thick sea ice cover, surrounding the North Pole that mainly distinguishes the Arctic from the Antarctic environment. Because of this marine character, extreme air temperature minimums rarely fall below -40° to -50° C over the vast expanse of perennial sea ice. In summer, this marine effect predominates even more. Variability at this time about a mean of 0° C is very slight.

ARCTIC RESOURCES

The Arctic consists of portions of Alaska, Canada, Scandinavia, and the U.S.S.R. plus Greenland and the adjacent water bodies. There is a wide range of resources, fossil fuels, and metallic ores in both northern U.S.S.R. and Scandinavia and in undersea settings offshore of these nations. It must be assumed, however, that their exploitation will be by these countries. Similarly what Greenlandic resource development takes place, notwithstanding a single mining operation under Canadian lease at present, will likely be under Danish or local Greenlandic control or both. Thus, Arctic maritime transportation opportunities that evolve, in the foreseeable future, will be associated with Alaskan and possibly Canadian resources which will be developed when economic forces dictate and not before. Consequently, this brief treatment of circumpolar resources is limited to Alaska and Canada. Figure 1 is a map of western Arctic resource locations.

Alaskan Mineral Resources

While Alaska has been frequently described as a vast treasure house of resources, from the standpoint of Arctic maritime transportation development, the range and distribution of these resources would appear to be limited to a few commodities in the northern and northwestern portions of the state. The present and potential demand for maritime services seems to be linked to selected mineral deposits situated in the regions from Bristol Bay northward and on the Arctic coastal plain, commonly referred to as the North Slope. Petroleum, natural gas, coal and a few metallics, notably copper, lead and zinc offer greatest promise for marine transport demand.

While the extent of both oil and gas reserves in Arctic Alaska, on-shore and off-shore, are still unknown, they are potentially very large. The Prudhoe Bay reserves alone are conservatively estimated at 9.4 billion barrels of oil and 764 billion cubic meters (27 trillion cubic feet) of gas. (Oil and Gas Journal, Vol. 75, No. 14, April 14, 1977, p. 56). Alaska is also known to have extensive deposits of generally low sulfur content coal, aggregating some 130 billion tons, the energy equivalent of 350 billion barrels of crude oil. (E.F. Barnes, Coal Resources of Alaska. U.S. Geol. Survey Bulletin 1242-B, 1967.) Prudhoe Bay reserves of petroleum approximately equal two years of current U.S. consumption of oil from all sources, including both domestic and imports. Its gas reserves, if somehow called upon to meet total American demands, would provide a one and half year supply at current levels. Alaska's coal reserves, on the other hand,

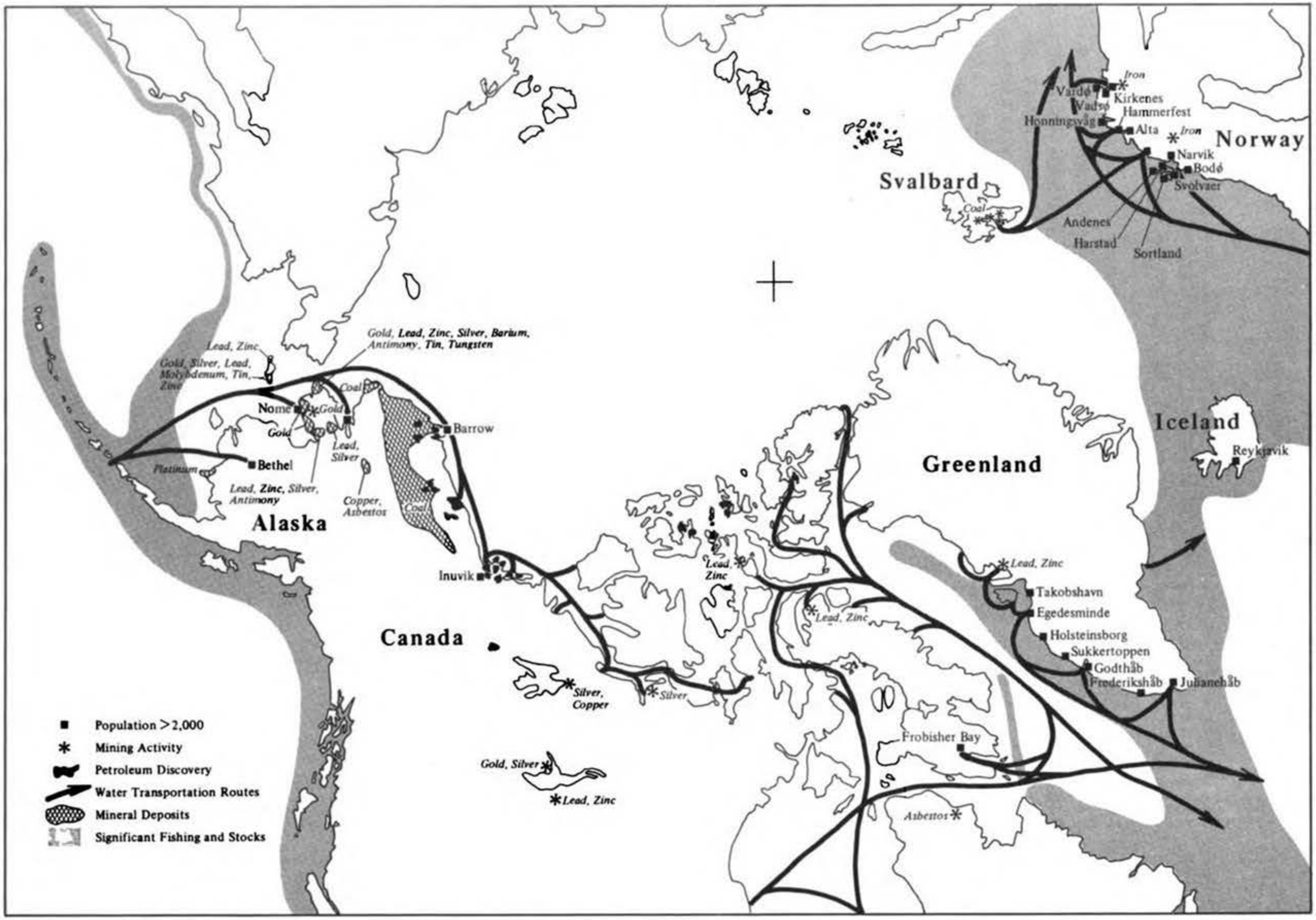

FIGURE 1 Western Arctic Resources

exceed five hundred times present national annual useage. Conversion of all recoverable Alaska coal to petroluem, were it feasible, would provide some one hundred oil years for the United States at present consumption rates. Over ninety percent of these reserves occur north of the Brooks Range and thus provide a major potential source of Arctic maritime transportation demand. Markets in Japan and other Far East areas, as well as those in the lower 48 states may be assumed to be the eventual utilizers of this marine transport opportunity.

High grade copper deposits near Kubuk and lead and zinc occurrences north of Noatak, both in northwest Alaska, indicate further potential Arctic maritime shipping. Much more research and exploration is needed before an estimate of the total metallic resource potential of north Alaska can be made. There is reason to believe, however, that extensive lead, zinc, copper and possibly other metals, in either concentrate or direct shipment form, should be anticipated as an eventual opportunity for U.S. maritime transportation.

Northern Canadian Mineral Resources

Northern Canada, herein operationally defined as the Yukon and Northwest territories including their off-shore area, stands as one of North America's resource frontiers. While the ancestors of contemporary northern native peoples have utilized renewable resources, animals, aquatic life, trees, plants, and the like, for many years, extractive energy sources and minerals are attracting today's commercial attention. Economic and geographic limitations preclude large scale commercial (and transport generating) development of forestry, fisheries, agriculture and grazing industries in Canada's north lands.

Mining, including oil and gas, is another matter. Gold, radium, and relatively small scale oil production have been part of northern Canada's economy for decades. Post-World War II developments in lead, zinc, copper, silver, nickel, tungsten, cadmium, and asbestos have followed. A combination of rail, truck, river barge, air and pipeline transport facilities have met all needs of the minerals industry of northern Canada until very recently.

In the late 1960's, as in Alaska, major exploration efforts for oil and gas came to the Canadian north. There is guarded optimism that the area will become, like Alaska's North slope, a significant production region within the foreseeable future.

Oil reserves in Canada's north at the 50 percent probability level, were estimated in 1975 at 18.8 billion barrels. This figure is still in use in 1980 by the Geological Survey of Canada (GSC). While this is a substantial total, it does fall significantly short of earlier optimistic industry estimates which ranged as high as 200 billion barrels. The 1975 GSC estimate for natural gas resources, also at the 50 percent probability level, stands at three and a half trillion cubic meters (123 trillion cubic feet), again much less than orginal industry estimates which were some two and a half to five times as great. Canada's total consumption of petroleum currently totals some 681 million barrels per year and annual natural gas consumption is 43.3 billion cubic meters. The far north could therefore, theoretically, serve as the nation's sole supplier of petroleum for almost 27 years and of natural gas some eighty years, based on GSC estimates of reserves.

Extensive reserves (in excess of 100 million tons) of direct shipment iron ore have been located in northern Baffin Island, as well as 7 million tons in lead and zinc deposits, from which production began during 1977 when the first concentrates were shipped to European markets.

At Coppermine a three-million ton copper deposit has been identified as well as substantial reserves at existing mine sites throughout the territories.

While various other mineral resources have been identified throughout the Canadian north, the cited examples are those for which oceangoing vessels are a logical and foreseeable transport mode.

Arctic Living Resources

In the Bering Sea, pollock is the main species fished. Total annual catches of almost two million metric tons (almost 3% of annual worldwide marine harvest) over the whole Bering Sea are made by all the fishing nations combined (CIA Polar Regions Atlas, 1978). Other commercial fisheries for which management plans have been developed under the U.S. Fishery Conservation and Management Act of 1976 (FCMA) are sable fish, herring, snails, king and tanner crab, shrimp, halibut, yellow finned sole, turbots, Pacific cod, rockfish, atka mackerel, and squid.

In the Beaufort Sea, there are no large commercial fishery resources. There are some small, localized, seasonal fisheries. Marine mammal populations, including bowhead whales, beluga whales, ringed and bearded seals, walrus, polar bear, and Arctic fox in the fast ice, flaw ice, or pack ice zone, are not hunted commercially, but only in some cases are hunted for native subsistence. They will not be a driving force for marine transportation development but instead will be potential conservation considerations. The bowhead whale is a particularly sensitive political issue. Many species of birds breed in the area and are present from May through September. They are not a commercial resource but are also potential conservation considerations (NOAA ERL, 1978).

There have not yet been fishery management plans developed by the U.S. under the FCMA for commercial fisheries in the Beaufort Sea. In Alaskan waters, the Bering Sea and the Gulf of Alaska are the areas with large commercially exploitable living resource populations.

In the Arctic Ocean, no commercial concentrations of fish have been identified to date.

The southernmost or North Atlantic section of the Labrador Sea is its most productive area. Fishing there beyond the 200 mile limit is regulated by the North Atlantic Fisheries Organization. The U.S. is not yet a member but negotiations to join are awaiting Senate approval. Fish resources include cod, haddock, and Atlantic herring which are fully utilized. Lobster is the greatest dollar value resource. Other flatfish, pelagic fish, and invertebrates are harvested, including some, such as sand lance and capelin, which are considered underutilized (Pinhorn, 1976).

Commercial concentrations of fish are found in the Barents Sea, with total catches high but somewhat less than those in the Bering Sea. The main species fished are cod, capelin, halibut, and herring (CIA Polar Regions Atlas, 1978). Most of the waters in the Barents Sea fall within the 200 mile zones of the U.S.S.R. and Norway. The remaining portions are now the subject of negotiations between Norway and the U.S.S.R. The large fishery in this area is not anticipated to involve U.S. activity for the foreseeable future.

Of the areas under study by this committee, the Bering Sea is the region richest in living resources potential. As with circumpolar areas generally, major fishing is practical only during the summer season.

Arctic Human Resources

The land areas bordering the northern polar seas are essentially regions of sparse population. Furthermore it seems highly unlikely, notwithstanding present and anticipated mineral resource development, that the far north will be the residence of much larger numbers of people. While there are a few examples (Murmansk and Arkhangelsk for example) of sizeable centers in the Soviet Arctic there are no communities over ten thousand population in the rest of the circumpolar realm.

Of Alaska's total population (1977 estimate 411,211) only some twelve percent (45,735) reside in the Census Divisions fronting on the Bering, Chukchi and Beaufort Seas. Aside from two military installations in the Aleutian Islands there are only four communities with populations over one thousand in the entire sea frontier; Bethel (2,416 in 1970), Nome (2,488), Kotzebue (1,696) and Barrow (2,104). See Figure 2. Of the combined population, 8,704 for these settlements, some 6,600 or seventy-six per cent are Eskimo. Throughout the balance of the region the Eskimo population is in even greater majority. Of the several Census Divisions included, only in the oil producing Barrow-North Slope has recent population change been significant. Overall, population more than doubled, due primarily to (mostly white) influx since 1970. For the region as a whole, population increase since 1970 has been due mostly to simple natural increase, and in most Divisions emigration during the period has offset almost three-quarters of the influx of new people into the Barrow Division.

The Canadian Arctic littoral region consists of much of the Northwest Territories and the Hudson Bay coastal areas of Manitoba, Ontario and Quebec.

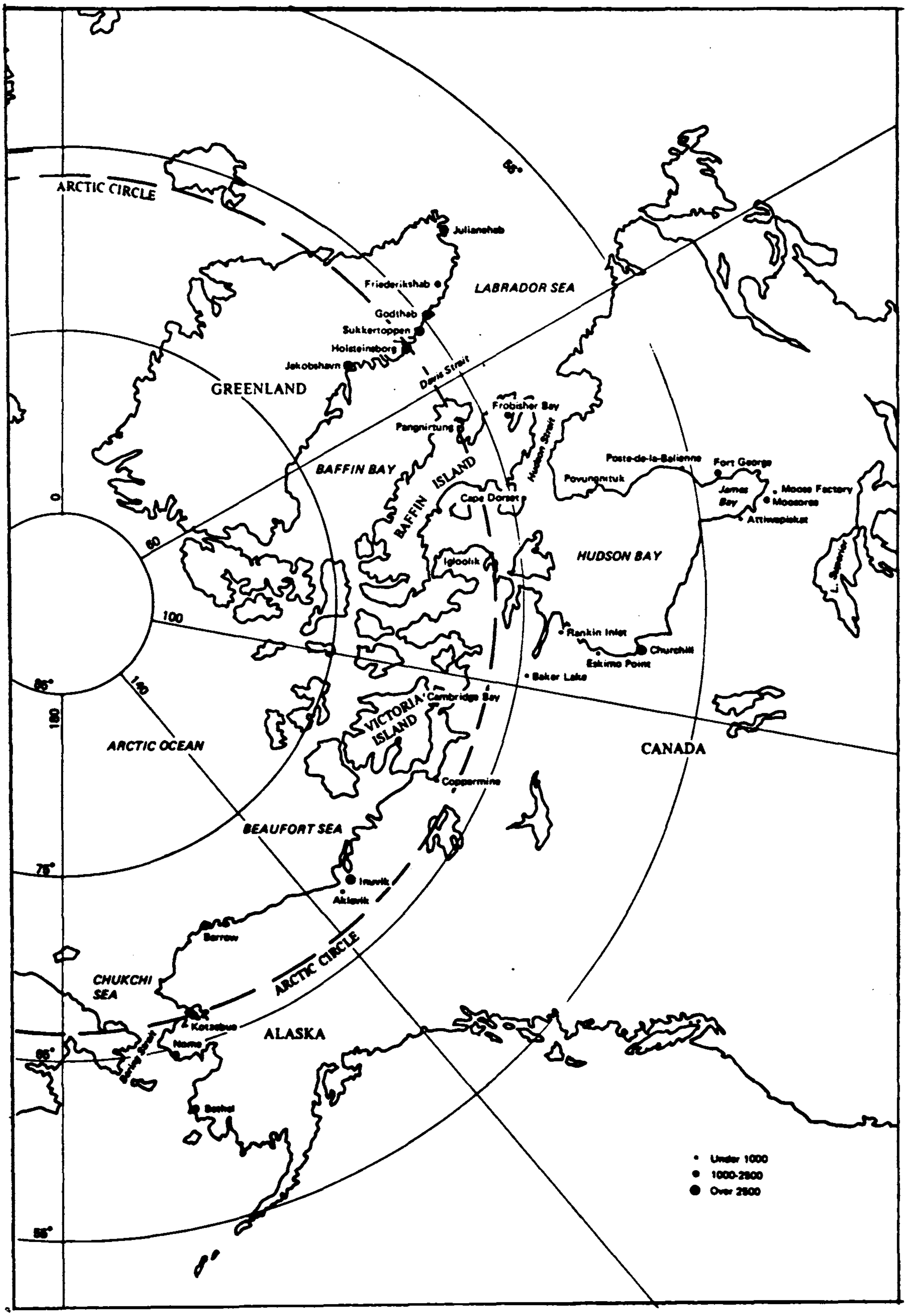

FIGURE 2 POPULATION DENSITY OF THE WESTERN ARCTIC

For the purposes of this population compilation the portions of the Northwest Territories included are the Mackenzie Delta, the north coast of the Mackenzie District and the entire Keewatin and Franklin Districts.

There are some 5,800 Mackenzie District residents in the Delta and coastal settlements. Largest is Inuvik (3,164 in 1975) followed by Aklavik (801) and Coppermine (756). Within the Franklin District (comprising the Canadian Archipelago and Melville and Boothia Peninsulas) the total population is 9,300, of whom nearly two-thirds (5,700) live on Baffin Island. Frobisher Bay (2,385) is by far the largest settlement of the District, with Pangnirtung (817) and Cape Dorset (706) the next in order on Baffin Island. Elsewhere in the Franklin District only Cambridge Bay (846) on Victoria Island and Igloolik (668) on the Melville Peninsula exceed five hundred individuals.

The France-sized Keewatin District, which lies north of Manitoba, contained only 4,216 people in 1975. There are no settlements with populations over one thousand and only three, Baker Lake (894), Eskimo Point (708), and Rankin Inlet (671) over five hundred. The entire coastal and adjacent areas of the Northwest Territories have a total population slightly over 19,300.

Manitoba's coastal population consists, for all practical purposes, of the 2,770 (1971 census) people of Churchill and Fort Churchill. The northern Ontario coastal region includes the settlements of Moosonee (1,793) nearby Moose Factor (849), Attiwapiskat (532) and a few very small, scattered communities. Total population for Ontario's Arctic coastal region is estimated at 4,300.

Hudson Bay's eastern shore area lies within the Province of Quebec. Major hydro-electric works are being constructed in the James Bay area of Quebec. The population associated with the construction is assumed to be dedicated to that undertaking so they are excluded from the Quebec totals included in the compilation. There are some 6,600 residents of the Quebec Hudson Bay coastal area. Largest communities are Fort George (1,280), Poste-de-la-Baliene (987) and Povungnituk (676).

The total population in the entire Canadian Arctic coastal region amounts to 33,000. Racially, about one-half are Eskimo, 15 per cent Indian, and the balance, primarily concentrated in the largest settlements, are white and other non-Native.

As of January, 1978, the population of Greenland, the world's largest island and Denmark's Arctic component, stood at 49,148, all of it coastal. Of this total, 40,609 were born in Greenland (essentially the Greenlandic people of Eskimo and mixed Eskimo-Danish stock) and 8,539 (17%) were born outside Greenland, nearly all in Denmark. From 1950 to 1970 the population of Greenland grew very rapidly, doubling from 23,000 to 46,000. In recent years however, this population growth has slowed.

A continuing demographic trend in Greenland has been abandonment of the smallest settlements (63 with populations under 100 in 1978 compared with 118 in 1950) and consolidation into larger communities. Godthab, Greenland's capital and largest city has grown from less than

4,000 in 1960 to 8,327 in 1978. Five other west coast communities, Holsteinsborg (3,757), Jakobshavn (3,423), Sukkertoppen (2,885), Julianehab (2,658), and Frederikshab (2,250) exceed 2,000 in population. Administration (primarily government), primary production (fishing, hunting and sheep breeding), and building-construction are currently the leading employment categories of the Greenlandic labor force.

In summary, outside the Soviet Union and northern Scandinavia (where coastal waters remain ice-free year round) Arctic coastal areas have small populations.

The combined population of Alaskan, Canadian, and Greenlandic coastal areas, including those inland communities that are oriented toward coastal activities, stands at less than 130,000. This widely dispersed population can, nonetheless, provide a modest local labor supply. Major manpower needs for significant expansion of production or services of any kind will, of necessity, rely on labor influx as has been characteristic of northern economic development to date.

FACTORS IN ARCTIC RESOURCE DEVELOPMENT

Existing Arctic Transportation

As this study is addressed solely to the polar regions, transport requirements for resource movement out of the southcentral and southeastern portions of the State of Alaska and its interior areas, such as the Fairbanks region, which have rail and highway connections to open water ports are excluded. Consequently, the forest and agricultural products of Alaska, which could generate additional needs for seagoing transport and are essentially restricted to these areas of the state, are not considered. Similarly the minerals of southeastern, southcentral and much of interior Alaska are not present nor future Arctic maritime transportation generators.

On the other hand extensive petroleum and natural gas reserves situated on the North Slope plus potential undersea deposits in the Bering, Chukchi and Beaufort Seas areas are of great interest to maritime shipping. Although the tankship MANHATTAN's transits of the Northwest Passage in the late 1960's did not lead to inauguration of maritime delivery of Arctic Alaskan oil, it did have positive results and was a most valuable research exercise. Present petroleum movement southward is entirely via the Trans-Alaska Pipeline System (TAPS) to the ice-free port of Valdez in southcentral Alaska for tanker trans-shipment. Future transport needs from expanded petroleum production on the North Slope cannot be satisfied by TAPS with its present pump station capabilities. There is no system, pipeline, liquid natural gas tanker, or other, for transporting the extensive natural gas resources of northern and northwestern Alaska to temperate zone markets, although a natural gas pipeline is presently being designed with the major engineering effort underway.

Oil and gas production in northern Canada began at Norman Wells on the Mackenzie River in the 1930's. Aside from the war years the limited production of this small field has been consumed regionally and has moved to local markets by barge.

Most Arctic oil and gas reserves are, by their geographical locations, capable of being moved to market by maritime transportation.

Launching of AMERICAN No. 1 on August 11, 1979, inaugurated a new era in American commercial fishing. This highly sophisticated trawler-catcher-processor is the first vessel of its kind in North America. It was designed primarily for use in the North Pacific and Bering Sea. Ships of this kind are expected to be competitive with foreign ships and can lead to substantial growth of U.S. fishing and an expansion of the industry.

It is to be anticipated that maritime transportation, which has not been used until recently to move northern Canadian mineral exploitation of Canada's northlands. Construction and operation of the bulk carrier M.V. ARCTIC attests to Canada's interest in such activity. Whether this development will bring about a requirement for U.S. maritime services will depend on institutional considerations as well as economic and physical constraints.

Social and Institutional Constraints

Although it is possible to analyze the impact of technological developments in the near future with some degree of confidence, it is with far less certainty that institutional, social, and econmic trends may be approached.

Perhaps the most important issues that will affect polar development and maritime transportation are political and jurisdictional--both international and domestic. Foremost among these is the lack of agreement over the jurisdiction and control of waters and submarine resources. At present only Svalbard, the Greenland-Canada boundary, and the U.S.- Russia convention line of 1867 exist under international treaty. Beyond these limited areas there is likely to be general disagreement between a sector principle, an equidistant line from coastal points, or control over the continental shelf. Until an agreement is reached, possibly emanating from the UN Conference on Law of the Sea (UNCLOS III), conflicting claims are likely to restrict exploitation of resources in disputed waters while each nation presses for its own advantage.

A similar problem exists in the designation of international waterways. Important to the United States is Canada's claim that the Northwest Passage is an internal water route and does not meet the standard international legal definitions of an international strait. Though open to the vessels of all nations, they must conform to Canada's various shipping and environmental acts. The United States disputes this jurisdictional claim.

Environmental considerations will certainly have important bearing on planning for polar development, too. At present Canada and the United States, cognizant of the fragility of Arctic ecosystems, are developing more stringent controls for shipping and off-shore operations. For Alaska these controls and procedures now require lead times of more than two years to meet environmental requirements before a project can begin and thus will increase uncertainties in planning and financial backing. Similarly Canada's Arctic is protected under several acts including the Arctic Waters Pollution Prevention Act, Navigational Waters Protection Act, Canada Shipping Act, and Wildlife Act among others.

A further ramification of federal regulations is likely to be the Jones Act in the United States and a similar clause of the Canada Shipping Act, both of which will restrict the use of foreign-built vessels to international voyages. Likewise, export controls in both countries may well inhibit the distribution of raw materials to foreign producers and consumers. Federal regulations may well conflict with state or territorial regulations over environmental safeguards or export controls.

Native peoples will be an important factor in planning for polar development. Through their corporations, they may prove to be a significant source of investment. They can also contribute a limited amount of manpower to construction projects. There is no doubt that increasing power and sense of self-control of native groups will require that northern developers carefully consider Natives' demands for compensation--both for losses of hunting areas and for qualitative changes in their lives (biological, social, and economic) resulting from polar develoment. It is likely, further, that they will demand a direct stake in development and may attempt to impose taxes on real property, vehicles, vessels, and incomes within their legal boundaries.

ARCTIC ENVIRONMENT

Physical environmental conditions for various Arctic water bodies are summarized briefly and compared in Tables 1 and 2. More detailed descriptions for U.S. Arctic waters appear in Appendix B and Appendix C.

Sea Ice

This section of the report necessarily deals in generalities because of the huge area covered and the wide variability of sea ice characteristics and extent.

Sea ice means different things to the various users that must work with it. This is especially true of the expanding community exploring for and developing polar resources. Those conducting exploratory drilling for oil and gas are interested in the nearshore ice conditions. Specifically they are interested in the so-called seasonal sea ice zone (SSIZ), the area within the average maximum and minimum annual limits of the pack ice extent. In winter they may be primarily concerned with the extent or boundary and thickness of the fast ice. Fast ice is the ice that forms first in shoal areas near the coasts and grows seaward. If drilling is to be done on fast ice, its thickness and strengths must be known. Although termed fast ice, small scale movements induced by such phenomena as wind, tides, storm surges, spring runoff and thermal expansion and contraction may occur. During summer--or in all seasons beyond the extent of fast ice--other ice features and processes are more important. Movement and dynamics of the ice become dominating influences. Such factors as the stage of development of the ice must be considered. An impingement of old ice that has survived one or more summers melt could obstruct operations. Deformation features, such as ridging are also major problems. Ridging usually occurs through alternate processes: convergent stresses cause fracturing, new ice forms in the fracture, subsequently crushing or shearing. As a result ridges attain thicknesses more than ten times that of undisturbed sea ice, whose maximum thickness is generally limited by thermodynamic ocean and climatic processes to about ten to twelve feet. These ridges can move rapidly, interacting with drilling structures and feeder lines from drilling structures to shore. Specific aspects of sea ice ridges that are important to drilling and other activities are their frequency, shape, height-to-draft ratio and whether they are grounded or free floating.

Transportation of resources depends on expeditious and safe transit to and from a commodity source. Concentrations of ice (amount

TABLE 1

Arctic Environment

	Average Depth	Major Rivers	Ice Cover	Ice Thickness	Ice Type	Tabular Ice (Shelf)	Superstructure Icing	Winds	Fog	Average Minimum Temperature	Circulation	Volcanic and Seismic Activity
Bering Sea	40 m	Yukon Kuskotoum	50% for five months	< 1m in North and Norton Sound	Winter ice	No	Very severe late fall through mid-spring	Peak in March > 34K for 15% of March	Frequent, especially in summer	-10°C	Cyclonic	High along S and W borders Destructive major events large Tsunamis
Chukchi Sea	45-50m	Noatak	Variable with polynyas and leads	2m-3m	Winter and old ice	Occasional	Very severe mid-spring and fall	> 34K, 10% of winter 97K - 100 yr maximum	Frequent over ice-free water 25% in winter in South	-42°C	North through Bering Strait, then East	Low, minor damages No dangerous Tsunamis
Beaufort Sea	< 200m	Colville Mackenzie	Nearly complete in winter	2m-3m occasional 30m ridge	Winter and old ice	Yes	Very severe early fall until freeze-up	> 34K, 5% of winter 81K-100 yr maximum	10%, during winter	-55°C	Clockwise gyre – weak N to E littoral current	Low, minor damage–no dangerous Tsunamis
Amudsen Gulf and Queen Maude Gulf	100-200m	Horton Hornaday	Complete in winter	1m-1.5m	Winter and some old ice	Rare	Very severe early fall until freeze-up	> 21K 6% of Sept 30% of W	Frequent	-55°C	Counter-clockwise gyre	Low, minor damage–no dangerous Tsunamis
Queen Elizabeth Islands	200-500m	Perry Simpson	Complete in winter	3m-3.5m	Mostly old ice	Yes	Rare – late summer and early fall	> 21K 5% Aug/Sep 12% Jan & Oct	Frequent	-51°C	NW to SE	Low, minor damage–no dangerous Tsunamis
Baffin Bay	2000m	-	Complete in winter	> 1m	Winter and some old	Occasional	Very severe late spring and fall	Variable	Frequent	-48°C	S. to N. on west side, N to S on east side	Moderate
Hudson Bay	200m	-	Complete in winter	> 1m	Winter and some old	Occasional	Very severe mostly fall, late spring possible in north	Variable	Frequent	-48°C	N to E	Moderate
Lancaster Sound	800m	-	Complete in winter	> 1m	Winter	No	Very severe late spring and early fall	Variable	Frequent	-48°C	Counter-clockwise	Moderate
Davis Strait	20-80m	-	Relatively ice-free	1m-2m	Winter, some old	Occasional	Very severe late spring and fall western portion – all seasons except summer, east side	> 21K Dec-Feb	Common May-Aug	-46°C	South	Very low, minor
Denmark Strait	500-1000m	-	Avg min. ice-free	3m-3.5m	Winter and old ice	Occasional	Very severe all seasons except summer	> 21K 9% of Jan.	Common	-23°C	Southerly along Greenland clockwise around Iceland	High large quakes threaten coastal development
Greenland Sea	150-3500m	-	Complete NE and NW of Greenland	2m-3m	Old ice and winter ice	Occasional	Very severe all seasons	>21K 10% Jan-Apr	Frequent	-28°C	Counter-clockwise	Many recorded on the Mohns Ridge Area
Norwegian Sea	300-3500m	-	Relatively ice-free	–	Some winter ice	No	Very severe – late fall through early spring	40K during Jan in North	Frequent	0°C	Counter-clockwise	Many recorded on the Mohns Ridge Area
Bovents Sea	200-500m	Pechorce Vashka	North and Central ice covered in winter – ice free in south	1.5-3m	Winter ice	No	Very severe all seasons except late spring and summer in south, only for fall in in north	40K during Jan in North	Frequent	-10°C	Counter-clockwise	None recorded

NOTE. Superstructure Icing can take place at times other than shown in Tables 1 & 2. Ice cover can attenuate seas and geographic restrictions can prevent sea development. Therefore, in some of these bodies of water during some seasons superstructure icing would not occur. Superstructure icing depends on air temperature, sea temperature, and wind conditions. It also depends on the freeboard of the vessel and the amount and type of superstructure. Finally, the degree of hazard to the vessel from superstructure icing will depend on the vessel length, its heading relative to the seas, and its center of gravity prior to and during ice accretion. To categorize superstructure icing occurrence, one must consider all of the above.

TABLE 2

Environment of Arctic Straits

	Width	Depth	Ice Type	Maximum Ice Thickness	Tabular Ice	Superstructure Icing	Currents
Unimak Pass	10 miles	64 to 91 m	No ice	–	–	Very severe–early winter through early spring	Tidal Current
Bering Strait	44 mi	18 to 42 m	Winter ice–old ice possible	1.25 m	None	Severe–mid-fall through early spring depending on ice cover–mostly mid-fall to late fall	North
Prince of Wales Strait	.5 to 2 mi	9 to 109 m	Winter ice–some old ice	3 m	Occ'l	Severe–early fall	Northeast
Viscourt Melville Sound	80 to 120 mi	146 to 585 m	Old ice–some winter ice	3 m	Occ'l	Severe–late summer and early fall if ice at minimum	East
M'Clure Strait	50 to 80 mi	347 to 512 m	Old ice and winter ice	3 m	Occ'l	Severe–late summer and early fall if ice at minimum	Southeast
Barrow Strait	30 to 50 mi	110 to 219 m	Old ice and winter ice	3 m	Occ'l	Severe–early fall–depending on ice cover	East
Lancaster Sound	50 to 80 mi	476 to 732 m	Winter ice and old ice	3 m	Frequent	Very severe–late spring and early fall	East
Dolphin and Union Strait	15 to 50 mi	18 to 91 m	Winter ice–occ'l old ice	2.5 m	None	Moderate–late summer and early fall	Southeast
Coronation Gulf	50 to 90 mi	15 to 91 m	Winter ice–occ'l old ice	2.5 m	Rare	Moderate–late summer and early fall	Southeast
Dease Strait	10 to 20 mi	18 to 91 m	Winter ice–occ'l old ice	2.5 m	Rare	Moderate–late summer and early fall	East
Victoria Strait	70 to 100 mi	36 to 91 m	Old ice and winter ice	3 m	Rare	Moderate–late summer and early fall	South and North
Bellot Strait	150 yards	137 m	Winter ice–occ'l old ice	2.5 m	Rare	Severe–early fall	Southeast
Prince Regent Inlet	50 to 60 mi	421 to 476 m	Winter ice–occ'l old ice	3 m	Rare	Severe–early fall	South
east of King William Island	15 to 30 mi	36 m	Winter ice–old ice possible	2.5 m	None	Severe–early fall	Southeast
Franklin Strait	15 to 30 mi	110 m	Winter ice–occ'l old ice	3 m	Rare	Severe–early fall	Northeast
Peel Sound	10 to 30 mi	214-796 m	Winter ice–occ'l old ice	3 m	Rare	Severe–early fall	North

of ice versus ice-free water in an observational area) then become of overriding importance along with the existence of and conditions within the pack, shore, and flaw leads. A shore lead is an area of largely open water between the pack ice and the shore. A flaw lead is an area of largely open water between pack and fast ice. These leads may or may not be refreezing or refrozen. Of course, ice thickness, strength, roughness, or deformation features are also of concern as are other features, such as floe size, stage of melt, snow cover and presence of glacial or ice island fragments. The seriousness of problems caused by the features and processes mentioned is related to the size, design, strength, and power characteristics of the carrier itself. Also of great importance is the position of the highly variable ice edge.

The maximum extent of sea ice varies widely from year to year and from locale to locale. The average maximum is shown in Figure 3. It is noteworthy that when the eastern Bering Sea is enjoying light ice conditions, the western Bering Sea and the Sea of Okhotsk may have heavy ice. It is also noteworthy that light ice conditions in the Bering Sea do not necessarily signify light ice conditions in the Beaufort Sea. Indeed, the reverse may be true in many years.

The chart of average minimum extent of sea ice, Figure 4, depicts the position of the sea ice pack in its usual position along the north coast of Alaska and in the Parry Channel. The Beaufort Sea itself can be broken into two distinct areas of relative sea ice severity; west of Prudhoe Bay and east of Prudhoe Bay.

Figure 5 illustrates the average thickness or stage of development of sea ice in different locales. In the near shore areas of the Beaufort Sea the predominate sea ice is winter or annual ice, which seldom exceeds six feet; however, it is not unusual for old ice to be interspersed within this winter ice with thicknesses over eight feet. This chart does not show the thickness of pressure ridges or shelf ice fragments. The figures shown are for relatively smooth sea ice.

Indeed, insofar as polar resource development is concerned, its effectiveness is completely coupled with understanding of sea ice behavior and distribution. Sea ice affects operations of the wide variety of current vessels and carriers and also affects development of marine structures and architecture. New vehicles for transiting sea ice are being developed by all countries bordering upon polar seas. Terminals, drilling mechanisms, and structures are also being developed.

Acoustic phenomena such as reverberation, ambinet nosie, and propagation are dependent on sea ice properties and distribution and are of interest to the Department of Defense, Various other government agencies are interested in such problems as the effect of pollution on ocean waters, sea ice, northern atmospheres and polar life forms, especially endangered species.

Today, the USSR, Japan, Canada, Iceland and Scandanavian countries are far ahead of the United States in taking advantage of Arctic fisheries. Hundreds of foreign ships, including factory ships, are extracting these riches from areas deep within the pack ice. For the United States to rely less on foreign imports of fishery products, we

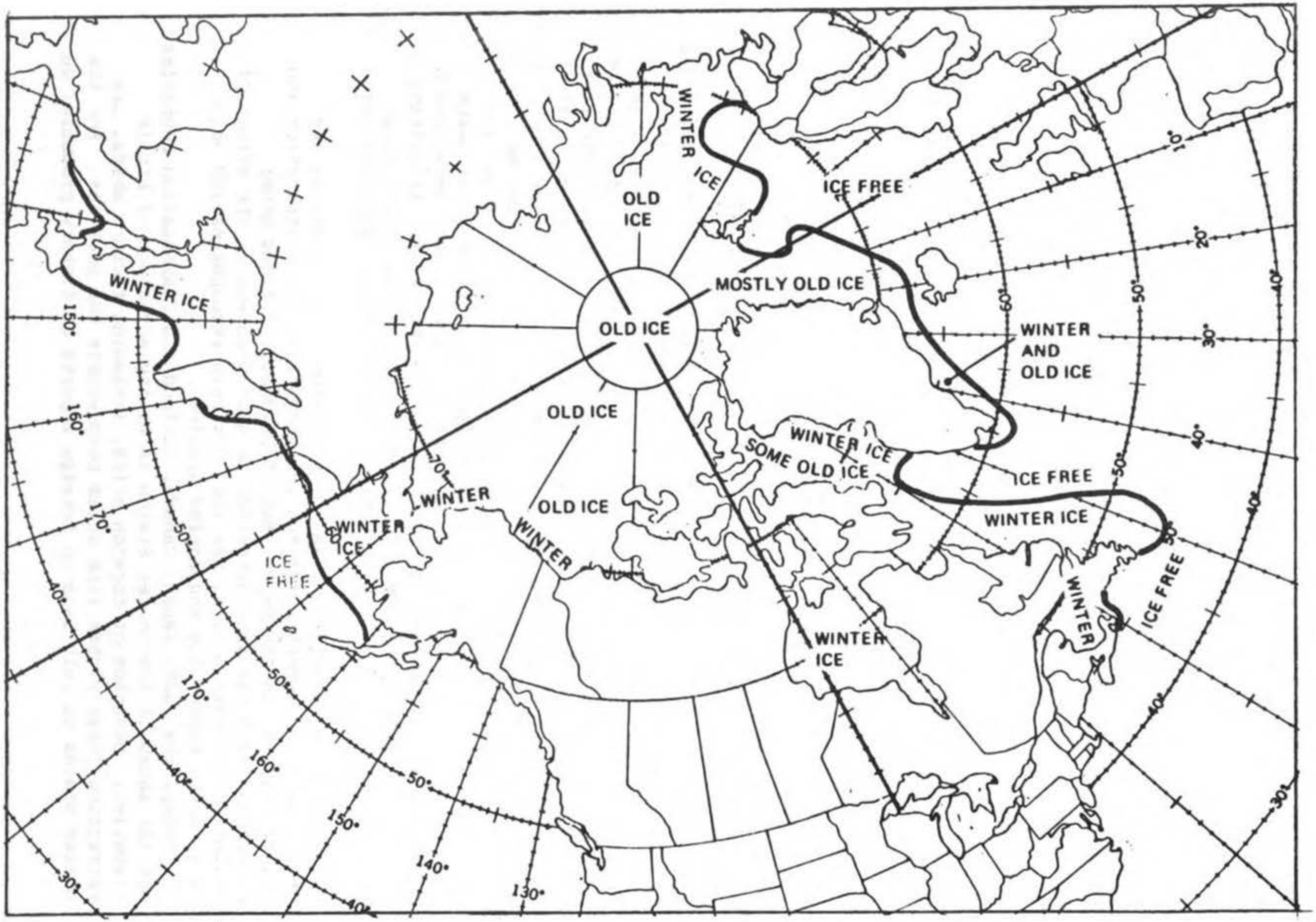

FIGURE 3 Average Maximum Extent of Sea Ice

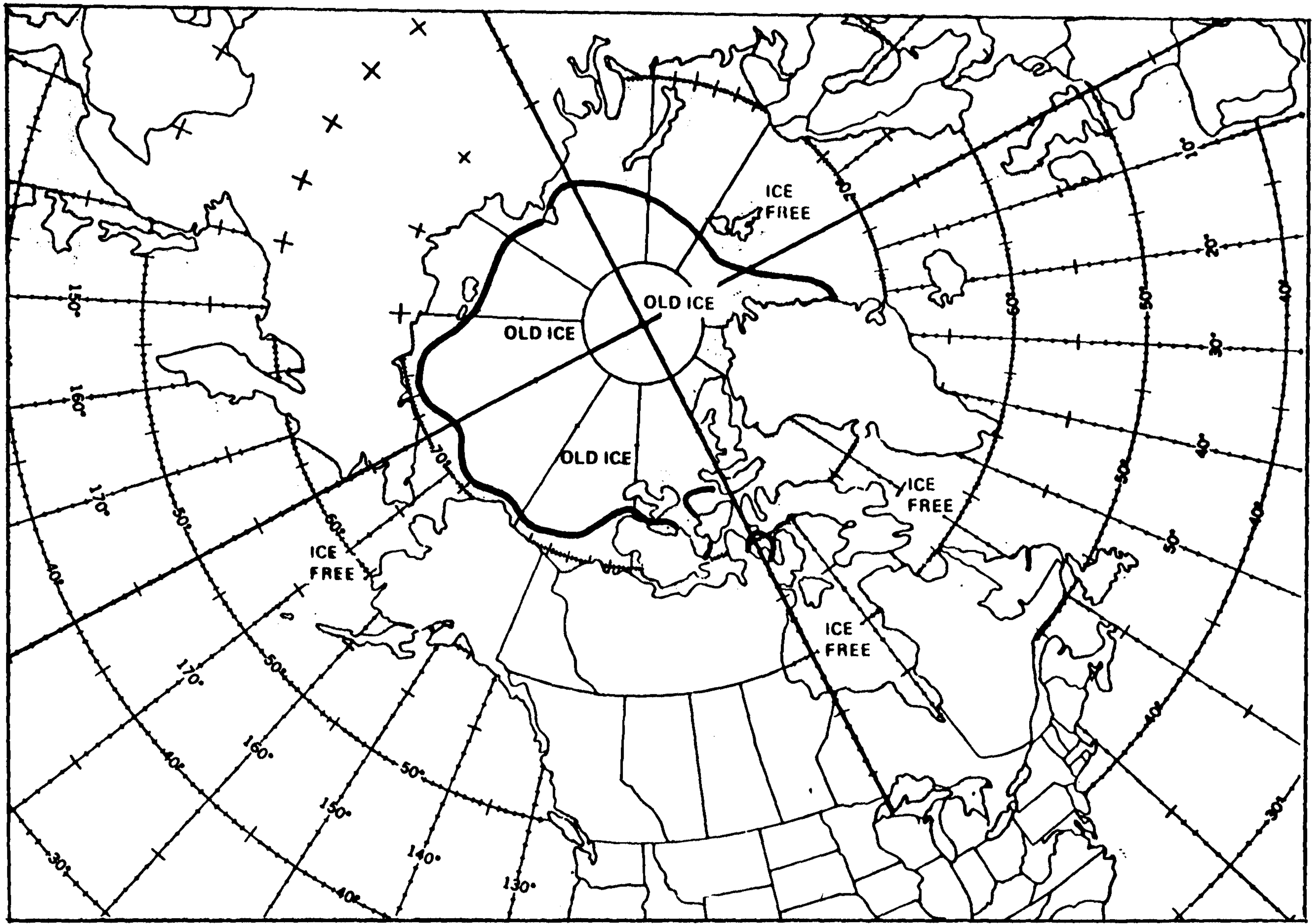

FIGURE 4 Average Minimum Extent of Sea Ice

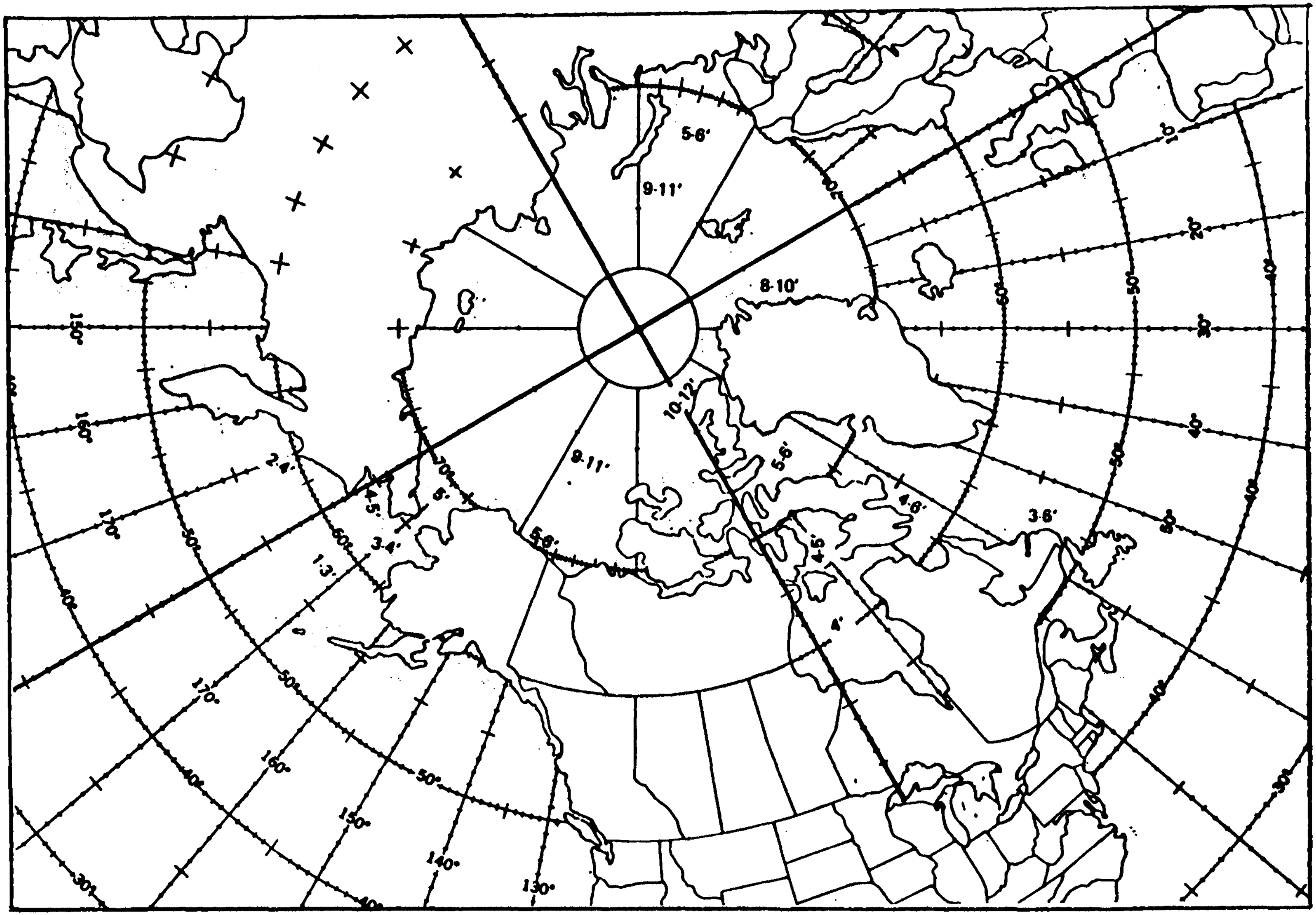

FIGURE 5 Sea Ice Thickness

must understand ice behavior and be able to operate in the ice. Here, edge, concentration, thickness, and ridging are the most important criteria.

Finally, in numerical modeling of ice dynamics--and especially in climate modeling, modification, and understanding--knowledge of the time/space distribution of ice features in both polar regions is a necessity. A major program to understand the dynamics of ice circulation in the Beaufort Sea, the Arctic Ice Dynamics Joint Experiment (AIDJEX) was undertaken between 1970 and 1978. However, it is disturbing that at this time, when space age technology has given us such tools as remotely sensed imagery and automated telemetering environmental data buoys for expanded understanding of ice, less ice data are being collected and systematically recorded than were collected in the past two decades. We should be collecting more data to improve development of energy, food, and other polar resources. New data buoy programs which are being proposed would be helpful as well as a polar orbiting satellite for ice studies.

Atmosphere and Currents

The mean annual sea level pressure chart, Figure 6, illustrates the primary centers of meteorological action in the lower atmosphere; the Aleutian and Icelandic lows. It also illustrates the secondary centers of action; the Pacific or Beaufort Gyre and the Greenlandic High. The position of these centers appears to be important to forecasting relative severity of ice in different areas during the coming ice season.

Figure 7 illustrates the major oceanic circulation in the polar areas. Note, that the primary and secondary centers of action in the lower atmosphere coincide with similar circulations in the ocean. There are other currents in the Arctic but they are not as pronounced and can quickly become wind driven currents when the wind speed is sufficient. In general these lighter currents circulate in a clockwise fashion around land masses or the bigger islands. Although the sea ice extent will vary from year to year, the same general contour is usually followed. This contour appears to follow the oceanic and lower atmosphere circulations.

Permafrost

Permafrost occurs commonly in high-latitude and high-altitude land environments and is found also in the sea floor along Arctic coasts. Because the characteristics of permafrost-soil structures are readily altered by human activity, permafrost poses many problems for construction engineering in regions that are prospects for resource development.

Much less is known about offshore permafrost than is known about land permafrost. Ability to predict the probable distribution of

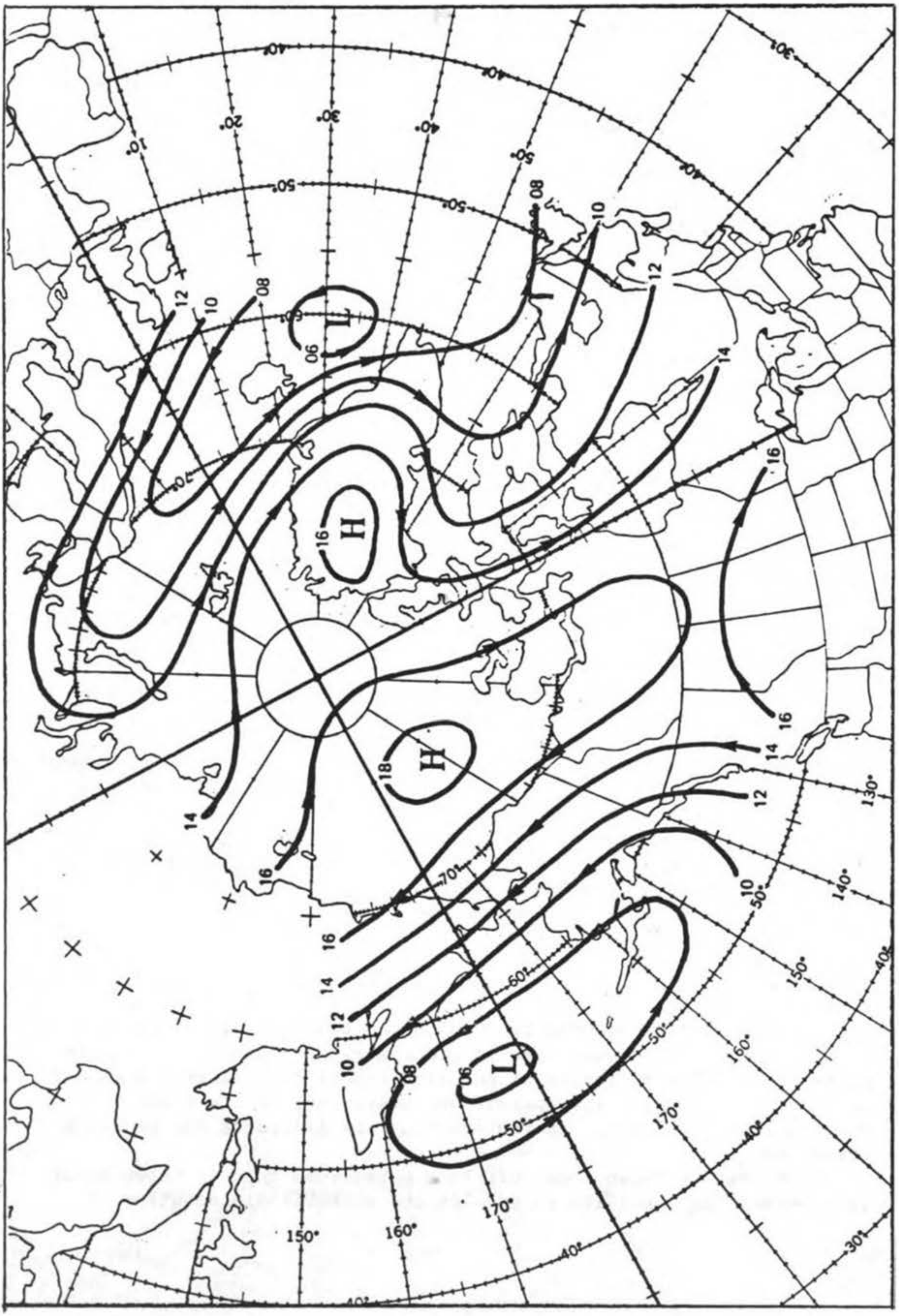

FIGURE 6 Mean Annual Sea Level Pressure

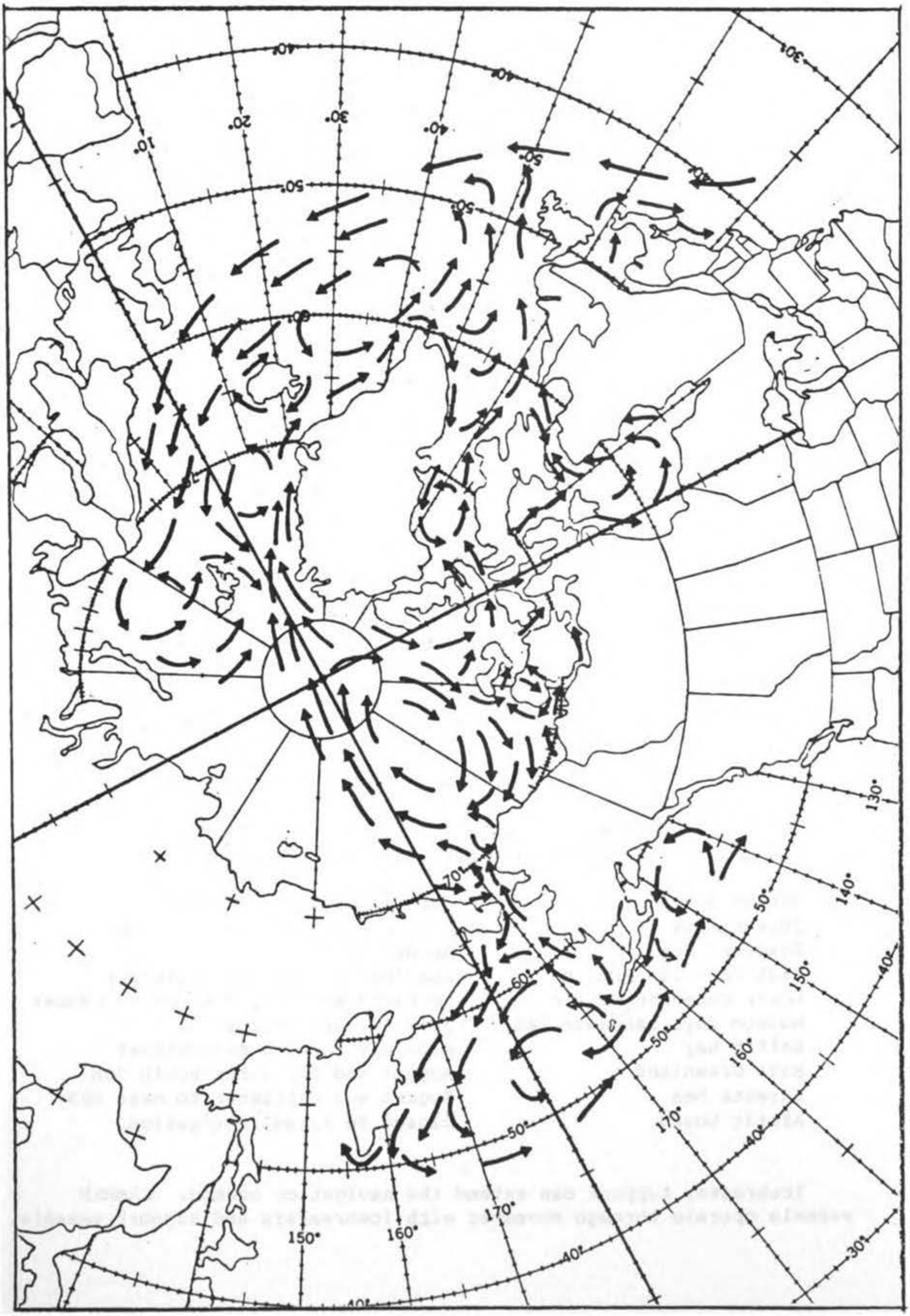

FIGURE 7 Major Ocean Currents

offshore permafrost is limited. The interdependence of thermal, hydrologic, and sedimentary factors affecting offshore permafrost is not well understood. Even if the role of these factors were better known, our knowledge of the general distribution of offshore permafrost would be limited by our inadequate knowledge of the distribution of bottom-water temperatures and bottom currents in the Arctic Ocean.

Scientific assessment of offshore permafrost has shifted from highly speculative to more specific in the past 20 years. Although the literature on offshore permafrost is sparse, it shows evidence of substantial permafrost offshore.

Exploration, extraction, and transportation of hydrocarbons will raise problems of engineering and construction related to the existence of permafrost in the off-shore areas and sea beds. Wells, offshore structures, and port facilities can affect the characteristics of permafrost-soil structures and may require special designs. Offshore operations can proceeed with greater confidence when more comprehensive knowledge of offshore permafrost is obtained.

Normal Navigation Seasons

The period of normal navigation by unescorted vessels varies widely and is dependent on several factors: (1) the strength of the vessel, (2) the draft of the vessel, (3) the experience of the master, (4) the support services (aerial reconnaissance and sea ice forecasting) provided, and (5) the ice conditions themselves. Some vessels may be safe operating in four tenths coverage of ice while other vessels may not enter ice with a concentration of over one tenth. Table 3, therefore, provides only generalities.

TABLE 3

NORMAL NAVIGATION BY UNESCORTED VESSELS
(VARIES WITH SEVERITY OF ICE SEASON)

Bering Sea	June through mid-November
Chukchi Sea	mid-July through mid-October
Beaufort Sea	August and September
High Canadian Arctic	Portions August and September
Lower Canadian Arctic	Portions mid-July through September
Hudson Bay, Labrador Sea	July through October
Baffin Bay	mid-July through mid-October
East Greenland	August and September south 70N
Barents Sea	August and September to near 80N
Arctic Ocean	closed to normal navigation

Icebreaker support can extend the navigation season. CANMAR vessels operate through November with icebreakers and support vessels assisting rigs in the southeastern Beaufort Sea and outer Mackenzie Bay. U.S. tug and barge operations can be extended into October, and possibly November, along the northern coast of Alaska by using icebreaking barges. U.S. icebreakers have been conducting Bering Sea winter patrols for several years. Soviet nuclear icebreakers have demonstrated their ability to penetrate the deep Arctic ice pack by reaching the North Pole on at least one occasion. Thus it is clear that Alaskan shipping seasons could be extended both in spring and fall in all areas if powerful icebreakers were available.

Four scenarios for ice transits through Arctic waters from the Pacific to the Atlantic appear in Appendix D: two transits by a deep draft vessel designated MANHATTAN II, drawing 18 to 22 meters (10-12 fathoms), one during optimum sea ice conditions and one during the most adverse sea ice conditions; and two transits by a medium draft vessel, drawing 7 to 9 meters (4-5 fathoms), under similar optimum and adverse sea ice situations.

The transits described in Appendix D are based on imaginary vessels. For scenario purposes a number of assumptions concerning their nature are made. They are assumed to be icebreaking carriers with an optimum power/strength ratio and other special design characteristics. It is further assumed that the masters of the vessels are experienced in sea ice navigation. Just as importantly, it is also assumed that support systems, such as icebreaker assistance and an ice observing and forecasting service, are available. Finally, it is assumed that the most sophisticated navigation and communication systems will be used.

CURRENT ARCTIC MARINE SYSTEMS

Ports

A port is defined as an interface between marine mode and any other transportation mode including marine, road, rail, pipeline, and air. If protection and anchorage for ships are provided as well, the term harbor is used.

Much of what follows can be found in a report dated July, 1973 entitled "Arctic Resources by Sea" prepared for Canada's Ministry of Transport by Northern Associates (Holdings) Ltd.

Port design or location will be based on the following three main considerations:

A. Operational Needs of Ports

1. Suitability for cargo; whether it is liquid bulk, dry bulk, or general cargo, or any combinations; will determine the basic configuration.
2. Facilities must meet the needs of the marine mode whether surface vessel, submarine, or semi-submersible.
3. Facilities must be a suitable interface between various modes involved.
4. Facilities for Customs, Documentation, and Administrative personnel must be provided.

B. Marine Mode Needs or Requirements

1. Security in approach, including pilots and navigational aids.
2. Safe anchorage, if ship is not able to tie up alongside upon arrival.
3. Dock that is secure from wind, ice, current, and wave effects and has adequate water depth.
4. Provision for crew replacement and recreation.
5. Quickest possible turn around.
6. Availability of weather and ice forecasts both in short and medium term.
7. Ship repair, ballasting, bunkering, and possibly oily water ballast separation.
8. Ice-freeing arrangements within harbor and approach area.

C. Cargo Needs

1. Surge capacity either at source or in port.
2. Security against theft, wind, cold, pollution, etc.; not a source of pollution to environment.
3. Facilities to prepare cargo for marine mode, if not intermodal upon arrival.
4. Verification systems for weight, quality, etc.

As the port is an integral part of the marine transportation system, it will influence the economic, environmental, and demand factors of the total system.

Present Arctic harbors, such as that at Churchill, Manitoba, use the same technology as warm water ports with minor modification, limiting their operations to the summer season when Arctic conditions are least severe. During this brief season, incremental costs at Churchill are approximately 35 percent above those of open water ports.

So far, northern ports have been located in natural harbors, such as bays or tidal estuaries, so that the land offers protection from winds, wave action, and currents. Artificial harbors protected by breakwaters can be constructed using existing technology. Costs of constructing artificial harbors would depend largely on local availability of construction materials. A protected harbor, either natural or manmade, is a requirement for either general cargo or bulk cargo loaded by a high speed loader. Either usually requires the ship to be alongside a conventional wharf.

Offshore single point moorings, designed to resist ice pressures, would be suitable for loading bulk liquids or slurries. Such moorings could be used for surface ships, submarines, or semi-submersibles where the water is sufficiently deep. Because less shelter is afforded, operations would be vulnerable to the severe wind and ice conditions that are normal in the Arctic. Detailed studies would be needed of each structure and site to satisfy all structural and environmental requirements.

Prior to choosing a port site, a study of navigation problems should be made. The study should cover the characteristic features of the ice regime including the river and sea approaches and routes. An estimate should be made of the increase in static ice thickness resulting from ship traffic in the harbor. The study of the ice and thermal regimes should be directed toward forecasting dates of ice break-up and freezing.

Research and development for Arctic terminals must consider the following in determining type of harbor facilities to be constructed.

1. Ice conditions and forces exerted by ice pressure.
2. Soil conditions, permafrost, allowable bearing pressure, settlement, etc. on shore and underwater.
3. Size and type of vessel to be berthed. Depth of water required in the dock and approach channel, together with appropriate ice-freeing arrangements.

4. Berthing forces and fendering; tug requirements Modifications to what would be needed for open water conditions to allow for ice conditions, extreme temperatures, and isolation should be included in design especially for tugs.
5. Mooring forces--including factor for ice jamming between wharf and ship. Automatic system for line tending will have to be considered.
6. Wind and waves--wind velocity and direction should be measured at site.
7. Current and tides--current suitable for ice flushing should be sought and studied.
8. Earthquake forces where applicable.
9. Thermal forces.
10. Dead load on structure--important where low-loadbearing soils are encountered. In addition, change in soil conditions due to perma-frost or possible modification of perma-frost must be studied.
11. Live load due to machinery, vehicles, uniform deck load, or from various structures built to serve specific requirements.
12. Topographic and hydrographic profile of the site considered.
13. Acessibility and distance to the resources to be developed.
14. Ecological, environmental, social, legal, and economic aspects.

Due to the above factors, extensive exploration and studies are required to arrive at the most favorable type and location of harbor and dock. Hydraulic model studies of wind, waves, and currents; aerial and on-land observations; and photography of the movements of the ice for one or two years would be necessary to establish the most favorable location and orientation for the harbor and dock.

In the report "Arctic Resources by Sea" 36 potential Canadian harbor sites were identified. The main criterion was water depth available at site. Factors such as ice characteristics, including pressure ridge depth and duration of open water, might have identified different potential sites in the Arctic.

Tugs and Barges

At the present time, tug and barge combinations, both ice reinforced and standard type, constitute the main Arctic marine transportation system that regularly, but mainly on a seasonal basis, serves the American and Canadian Arctic. This service started in the mid-fifties and now provides regular service to various government agencies and native communities scattered throughout the whole Arctic.

The Bureau of Indian Affairs, for many years, has provided marine cargo service to the native villages in the Bering Sea region and as far north as Point Barrow. The Bureau operates the M/V NORTH STAR III, a diesel-powered Victory type vessel of 7600 gross tons making two trips a year. This past year 12,000 tons of dry cargo and 7500 tons of petroleum were delivered, using four landing craft (LCMs) to deliver to the shore from the NORTH STAR III.

Since 1954, the U.S. Navy Military Sealift Command has contracted for tug and barge service to haul petroleum and dry cargo to the defense and communication sites of the Distant Early Warning Line (DEWLINE) and to resupply government installations of the Alaskan Air Command, Coast Guard Stations, Federal Aviation Agency, Fish and Wildlife Service, and the U.S. Weather Bureau. These site locations extend all the way from the Bering Sea north to Point Barrow and thence east to the Canadian border. None of the sites have docks or other conveniences, requiring lighterage equipment and heavy terrain vehicles for delivery to the sites. The barges range in size from 280 feet to 400 feet and are equipped to carry bulk petroleum, dry cargo, and lighterage equipment consisting of small craft and heavy trucks and trailers. Also, onboard are complete quarters for the longshore crews and tankermen. Deliveries follow seasonal ice breakup and continue through mid-September and as late as early October.

The barge and tug service has replaced almost completely the previous method of having either standard cargo ships escorted by ice-breakers or very small (50 to 200 ton) ships supply the area.

Annual transport includes various general cargo, from needles to heavy construction equipment, and heating oil.

With the discovery of the North Slope Oil Field in 1967 and the on-going drilling programs in the Arctic, tugs and barges have come into their own to deliver living quarters, power stations, and service buildings of modular construction. This method is quite suitable as most Arctic sites are without wharves and other conveniences, and also have a limited water depth. Some modules are nine stories high and can weigh up to 1200 tons each. Using specialized equipment, they are "walked" on and off the barges. Recently, a barge with icebreaking capability has been introduced into this service. Tonnages carried and equipment used in petroleum sea lifts on the North Slope are shown in Table 4.

TABLE 4

NORTH SLOPE OIL FIELD CARGO AND EQUIPMENT

YEAR	TONS	VESSELS
1970	187,000	
1971	30,000	6 ocean-going barges, 3 tugs 4 lighter tugs
1972	5,000	2 barges/1 tug
1973	21,500	8 barges/4 tugs
1974	70,000	14 barges/7 tugs
1975	160,000	43 barges 7 lighter tugs 13 lighter barges 2 crane barges
1976	72,000	22 barges 12 tugs
1977	44,000	8 barges/5 tugs
1978	38,000	11 barges/10 tugs
1979	8,000	2 barges/2 tugs

Arctic Icebreaker Operations

Until now it has been possible to meet Arctic cargo commitments during the summer season when sufficient open water appears in some locations to permit penetrations by shipping. In a large measure, then, the barrier posed by ice has been avoidable. But now, with accelerating commercial development, the situation is changing. Existing commitments will not only continue, they will expand. Important new ones are also appearing.

To meet this situation, the need to expand marine operations and extend the navigation season is imminent. A requirement for year-round operations into selected locations will not be far behind. Supporting all this activity is the icebreaker. It will continue to play a key role in the ongoing development of the far North. There are now too few icebreakers to meet present commitments and the fleet is aging. Some units suffer from inadequacies (e.g. low endurance) that lessen their effectiveness and none is able to extend the navigation season beyond its present limits to a significant degree.

Icebreakers are specialized vessels that fill an essential role. Without their services the present commercial shipping operations through ice during the summer or any season would be out of the question. Icebreakers are costly vessels because they require great strength, very high powers and long endurance. The trend in icebreaker design is toward even more powerful and larger ships than their predecessors. Table 5 lists the major heavy icebreakers of the world and their principal characteristics.

The primary role of the existing icebreaker has been, and remains, escort of commercial shipping through ice. Such shipping consists of unstrengthened vessels and vessels with a degree of ice-strengthening from Lloyds Ice Class 1 to Ice Class 3 or equivalent rules of the American Bureau of Shipping and other classification societies. Their size can vary from 1,000 tons or so to as much as 42,000 tons or more. The upper limit is usually governed by the beam of the escorted ship for if it exceeds that of the icebreaker, and the escort operation must be conducted, for example, through fast ice, quite obviously the larger ship will experience difficulties and may even suffer damage to framing and shell plating. Such an escort role is well established and will continue to be used during the summer navigation season, whether extended or not, to conduct convoys to and from selected unloading sites in the north.

A secondary and largely Canadian role has been to deliver cargo to remote northern stations. This commitment has been downgraded in recent years because the quantity of cargo that could be embarked was not especially significant, better means became available and, most importantly, such commitments interfered with the primary role of the icebreaker. In addition, structural strength in an icebreaker is jeopardized somewhat by having a large void space for cargo in a location in the hull where strength is essential.

TABLE 5

Major Heavy Icebreakers of the World

Country	Type or Class	Shaft Horsepower	Length Overall (ft)	Beam (ft)	Full Load Draft (ft)	Full Load Displacement (tons)
USA	POLAR CLASS (2)	60,000	399	83.5	30.8	12,688
	WIND CLASS (2)	10,000	269	63.75	28.4	6,260
	GLACIER	21,000	310	74	28.1	8,678
ARGENTINA	GENERAL SAN MARTIN	7,100	279	61	21.0	5,301
	ALMIRANTE IRIZAR	16,200	391	82	31.2	14,900
CANADA	LOUIS ST. LAURANT	24,000	366	80.3	29.5	13,300
	JOHN MACDONALD	15,000	315	70.3	28.1	9,160
	LABRADOR	10,000	269	63.8	30.1	6,940
	d'IBERVILLE	10,000	310	66.8	30.4	9,930
	NORMAN McLEAD ROGERS	13,600	295	62.8	20.0	6,320
	"R" CLASS (2)	13,600	316	64.0	23.5	7,235
	*AML X4	16,400	299	63.5	28.1	7,000
FINLAND	URHO (2)	22,000	343	78.1	27.25	7,870
	TARMO (3)	12,000	277	69.5	20.3	4,890
	VOIMA	10,500	274	63.6	21.0	4,415
JAPAN	FUJI	11,760	328	72.2	27.2	8,035
SWEDEN	ATLE (3)	22,000	343	78.1	27.25	7,870
	NJORD	12,000	284	69.5	20.3	
	TOR	12,000	277	69.5	21.3	5,230
	ODEN	10,500	273	63.6	23.0	5,303
	YMER	9,000	258	63.3	21.0	4,265
USSR	**ARKTIKA (2)	75,000	525	82.0	33.5	25,000
	**LENIN	43,400	439	90.5	30.2	15,750
	YERMAK (3)	36,000	442	85.3	36.1	20,241
	MOSKVA (5)	22,000	400	80.3	31.2	15,340
	KAPITAN (3)	10,500	273	63.7	23.0	5,350
	SIBIR (2)	10,050	351	75.5	22.0	11,000
	KAPITAN SOVOKIN	22,300	421	84.0	27.9	?

NOTES: 1. Numbers in parentheses refer to the number, other than one, of vessels in the class.

2. Primary operating area of some icebreakers is not necessarily the polar regions. For example, Scandanavian icebreakers operate primarily in the Baltic.

*Commercial icebreakers

**Nuclear-powered icebreakers

Not only do icebreakers escort shipping through ice in the summer on a planned basis, but they also are on call to assist unescorted ships that, for a number of reasons, get into difficulties and call for help. They also carry out scientific tasks (including all-important hydrography and oceanograpy) on a 'not to interfere' basis.

Success in ice breaking calls for both thrust and inertia. Thrust is the horsepower developed by the propellers and mass is the quantitative measure of inertia. What is required, then, is the best mix of horsepower and displacement for the area of operations and the season of the year.

Thrust is needed to drive a ship through a level sheet of fast ice on a continuous basis, while it is inertia that keeps the same vessel advancing through harder and thicker multi-year ice ridges and hummocks that are common features in ice fields.

MANHATTAN, at 155,000 tons and 43,000 shaft horsepower (shp), had the needed mass but too little thrust for other than an experimental voyage. The new U.S. Coast Guard icebreaker, at 12,000 tons and 60,000/75,000 shp, would seem to be the opposite. Icebreaker tankers considered at one time by Humble Oil for shipping Prudhoe Bay oil through the Northwest Passage were to displace about 250,000 deadweight tons (dwt) and develop about 200,000 shp. Those ships would have been excellent icebreakers for, all other things being equal, they would have had what presently appears to be the ideal combination of power and mass.

Canada's newest and most powerful icebreaker, the LOUIS S. ST. LAURENT, displaces 14,000 tons and develops 24,000 shp. During special trials on the second MANHATTAN voyage in 1970, this combination of power and mass failed to break a level sheet of fast ice four feet thick. The ship charged this obstacle and advanced about a ship's length before being brought to a standstill. The only way she could advance was by backing and ramming. In the same conditions, the MANHATTAN herself was equally unsuccessful.

Arctic first-year ice attains a thickness of approximately six feet. If there is to be an icebreaking capability over a longer period of the year, if not year-round, and over a wider area of operations than has been attempted up to this time, then icebreakers possessing materially better capabilities than those possessed by the ST. LAURENT are called for. In addition to first-year ice, there are also quantities of multi-year ice and ridging which present an even more redoubtable obstacle. The type, thickness and distribution of sea-ice in all its forms is dealt with in detail elsewhere in this report.

The United States Coast Guard embarked on an ice breaker construction program in 1966 because of the demonstrable inadequacies of their old Wind-Class ships. The need for better icebreakers became even more obvious during the Northwest Passage voyage of the MANHATTAN, in 1969, when the chief icebreaker role had to be assumed by the Canadian Coast Guard Ship JOHN A. MACDONALD.

The first new U.S. icebreaker built since 1955, POLAR STAR, was launched in 1973 and entered service in 1974. The second ship of the class, the POLAR SEA, entered service in February, 1978.

Experience with the icebreaking tanker MANHATTAN demonstrated that large ships, designed as such, would make the most effective icebreakers. Such ships would combine the qualities essential for success in ice, namely, mass, and power, making possible year-round navigation on a routine basis into selected Arctic areas and extended seasons into a number of others. These ships would be icebreakers in nearly every sense of the term and their performance in ice would exceed by a wide margin that of any present government icebreaker but may not be as maneuverable. They should not be confused with ice-strengthened bulk carriers which would not possess the desired qualities.

Year-round Arctic navigation would seem to be justifiable on three counts; firstly, a requirement to remove very high tonnages of minerals such as iron ore; secondly, the removal of natural gas in liquid form if the economics of such a marine operation can be justified; and, lastly as an alternative mode of oil transportation.

One mining project that could require year-round shipping (10-12 months) is the Baffinland iron deposit where the amount of direct shipping ore to be moved would probably exceed five million tons. However, factors of economics and marketing are not now favorable for development of this deposit, although world demand for steel and the political stability of the emerging source countries could change this state of affairs very quickly.

There is, therefore, no requirement at this time for ice breaking bulk carriers. However, demand for energy will continue to spur the search for more gas and oil. The situation could change very suddenly, placing strong emphasis on Arctic resources and a need for icebreaking tankers.

The Arctic Marine Employee

Government contracted tugs and barges have been servicing the DEWLINE since 1954, and since 1970 tugs and barges have been the main support and supply line for the development of the Alaskan petroleum industry. During the past 24 years, the number of employees in U.S. marine crews has varied from a low of 40 to a high of 325. Increasing activity in petroleum exploration suggests that employment growth will continue approximately through 1985. The importance of these figures is that for the number of employees involved in discharging and beaching cargo amounting to hundreds of thousands of tons under rigorous conditions, no deaths and few serious physical injuries have resulted. This would appear to indicate that the Arctic can be a safe working environment.

In selecting crews for Arctic operations, qualifications the employer must consider should include:

1. All employees should be required to pass a thorough physical examination.

2. Employees should be able and willing to endure long working hours throughout the short working season.
3. Preference should be given to employees with prior Arctic experience.
4. Because of the inaccessibility of ports for crew reliefs, the employee should be expected, and be willing, to remain throughout the season.
5. In addition to the normal skills required of seamen, crew members need other special skills, such as: heavy equipment operator, crane operator, welder, skin diver and tankerman.

Every marine crew member should either possess or be furnished with an abandon-ship survival suit and should be drilled in its use under adverse conditions. History has shown that most unprotected men who have found themselves in cold water, even when buoyed by life preservers, have died before they could be rescued. However, men have survived with abandon-ship survival suits for nine hours in water at a temperature of 35° F (2° C) and for 25 hours on a frozen beach. The abandon-ship survival suit is not a working suit. Also, each crew member should possess or be furnished a work-type survival suit that allows full freedom of movement, protection against extreme weather, indefinite flotation and adequate protection against hypothermia.

Although all vessels operating in the Arctic are equipped with inflatable life rafts, it is important that crew members be given special training for boarding. All life rafts should be equipped with "space" type blankets, in addition to the standard ocean equipment, to provide extra warmth onboard the life raft.

Because of the short operating season in the Arctic, crews are required to work long hours and a seven day work-week is the rule rather than the exception. Consequently, it is necessary that every effort be made toward favorable living conditions onboard. At present, all vessels are equipped with fresh water makers, because even though fresh water is available from the many streams and rivers that empty into the sea, offshore areas are so shallow that a vessel cannot anchor close to the beach. Extra provisions, both perishable and otherwise, are carried in refrigerated cargo vans onboard the barge. However, it becomes necessary at times to reprovision via airlift from trading points that are generally located great distances from the job sites. These, in turn, may not be near a landing strip. Notwithstanding these difficulties, high quality food is provided in abundance and, because of long hours, four meals a day has become a common routine.

Personnel records show that many employees regularly seek the annual Arctic resupply and sealift voyages. Even though the hours are long and the work is hard, the high earnings make it possible to earn a respectable annual wage in a few short months. Many also find the Arctic environment interesting and the challenge rewarding.

The outlook for employment in the Arctic tug and barge industry is for increased activity through 1985, including offshore petroleum exploration and development.

Recent oil discoveries in the Point Thompson and Flaxman Island areas of the Beaufort Sea could establish requirements for large sea lifts during the 1980's.

From past records it appears that the carriers are experiencing yearly tonnage increases. New oil or gas discoveries or drilling programs provide a one or two year rapid increase but tonnage then returns to more normal growth patterns. This growth pattern is expected to continue for the next ten years.

AUXILIARY SUPPORT SERVICES

While ports and vessels are the major components of any maritime transportation system, successful establishment and functioning of a transportation system depend upon a number of support services. The vessels and ports must communicate with each other as well as third parties. Vessels must be capable of proceeding in a safe and timely manner to their destinations. Resources in the form of personnel, equipment, and other supplies must be transported to establish and maintain port and production facilities and operations. Although some degree of self-sufficiency, in terms of these functions, is inherent in ports and vessels, auxiliary support services are generally relied upon to fulfill the bulk of these needs. This section addresses some of the more important support services for an Arctic marine transportation system.

Communications

Any Arctic marine transportation system will necessarily depend heavily upon reliable short-range (line-of-sight) and long-range communications. Short-range communications requirements can likely be satisfied by an expanded VHF-FM communications network and, perhaps, a shore network (e.g., marine operator) for ship-to-shore communications.

While short-range very high frequency (VHF) and ultra high frequency (UHF) communications are not impaired by polar-unique conditions, longer range high frequency radio communications are unreliable due to polar atmospheric conditions. For limited traffic levels, shoreside landline relay at remote sites may be sufficient; however, as traffic levels expand and/or as communications requirements dictate, it may be necessary to implement a communications system capable of rapid and reliable handling of not only operational traffic but also data transmissions between Arctic and temperate stations.

Communications satellite technology appears to be the most promising means for satisfying the long-range communications requirements. Existing maritime satellite services do not, however, provide coverage to the Beaufort Sea and northern Canadian Archipelago since current communication satellites are positioned in equatorial geostationary orbits to provide coverage of the major ocean areas. A network of satellites in polar or near-polar orbits would be necessary for adequate communications services for an expanded marine transportation system.

Navigation

The practice of marine navigation, i.e., the determination of one's geographic position on the water, in the Arctic regions is impaired by several factors. Because of the remoteness and limited marine activity in these regions the waters are relatively poorly charted and coverage by either traditional or modern electronic aids to navigation is limited. The low relief and featureless terrain characteristic of much of the Arctic coastline hinders navigation by traditional radar and visual means. Moreover, application of visual piloting methods as well as celestial navigation is limited by the inhospitable Arctic weather. High latitudes also place restrictions on use of magnetic and gyrocompasses and on celestial navigation. Navigational light and buoy systems, the heart of navigation systems in restricted waters in temperate regions, are precluded, or at least limited, by the ice and environment of the Arctic. In short, the utility of traditional navigational methods in both restricted and open waters is significantly diminished in the Arctic.

To overcome these limitations on conventional methods, current Arctic marine traffic relies upon satellite navigation, OMEGA, and installed shore aid systems, such as the system of RACONS along the Alaskan North Slope, to supplement traditional navigational methods. Only satellite navigation provides coverage throughout the Arctic. As Arctic marine commerce expands, accurate and reliable marine navigation over larger portions of the Arctic will become critical. Consequently, the limited navigational capability in the Arctic will require upgrading to assure safe navigation. Existing systems (e.g., the Alaskan RACON System) may require expansion. Increased use of satellite navigation and possible expansion of LORAN C coverage will likely provide adequate navigation coverage to open water areas. The continued movement of tug and barge traffic along near-shore open water passages and the future emergence of deep draft surface or submarine Arctic carriers will place a premium on accurate and comprehensive bottom sounding information. Most of the existing hydrography in Alaskan waters north of the Aleutian Islands does not meet National Ocean Survey spacing criteria. Similarly, the quality of bottom profiling in the Canadian Arctic is generally far below that in temperate regions. The known presence of significant and relatively abrupt rises in the bottom of normally deep Arctic channels further emphasize the need for good sounding information.

Provision of adequate navigation in restricted Arctic waters and approaches to harbors or offshore terminals will require development of substitutes for the buoy and shore aid systems utilized in temperate waters. Candidate systems for such substitution include:

1. high frequency radio systems (e.g., several commercially available systems are currently used for survey and experimental work);
2. low frequency radio systems (e.g., mini-LORAN C and DECCA systems);
3. acoustic systems (i.e., bottom-anchored acoustic transponders interrogated by a vessel-generated acoustic signal); and

4. leader wire systems (i.e., electronic tracking along a buried or sub-surface wire).

All of these systems lie within state-of-the-art technology. However, adaptation of particular systems to the Arctic marine environment may generate research needs.

Environmental Information Services

While icebreaker assistance is required to permit commercial vessels to deal with the ice conditions encountered, weather and ice information services strive to optimize vessel movements by helping the commercial carrier avoid adverse environmental conditions. An environmental information service performs three fundamental tasks: data collection, analysis, and dissemination. The product information is of two forms: (1) operational data that describe local conditions and is immediately applicable to ongoing operations, and (2) forecasts that are useful for vessel route planning and scheduling. Though different in the degree of detail required, the information requirements for ice navigation are generally the same for both operational data and forecasts. They may include the usual marine weather information as well as ice age and thickness distribution, ice ridging distribution, iceberg and floeberg information, grounded fast ice limits, and the location of leads, polynyas, and fracture zones.

Logistics

Other than the resupply of military installations, polar marine logistic needs have been associated almost exclusively with scientific research efforts. The transport of relatively small quantities of scientific equipment, supplies, and personnel among or between ice camps, vessel platforms, and shore stations has been a major logistics activity. The principal vehicles for fulfilling these logistics needs have been icebreakers, helicopters, small aircraft, and conventional land-carriers, such as tractors, trucks and snowmobiles. Each of these vehicles has obvious limitations. The use of large, expensive icebreakers is clearly cost-effective only for large-scale (in terms of cargo quantity and distance) logistic needs. Airborne carriers have limited payload capabilities and are highly weather-sensitive. Aviation is expected however to continue to provide the predominant personnel transport system in the Arctic. Land-carriers are generally limited to land-fast ice where open water areas and topography (ridging and hummocking) characteristic of the dynamic Arctic pack are not prevalent.

As Arctic marine scientific and commercial activity expands, logistic support requirements will also increase. Offshore platforms may require periodic deliveries of supplies and personnel from shoreside staging points. Regular and emergency servicing of offshore installations, including platforms and pipeline systems, may generate a need for utility vehicles capable of reliable service under the most adverse Arctic conditions. The limitations of traditional Arctic logistics vehicles will necessitate development of vehicles more capable of fulfilling these emerging needs.

Candidates for Arctic logistics vehicles include hovercraft [air-cushioned vehicles (ACV) and surface effect vehicles (SEV)]; vertical/short take-off and landing (V/STOL) aircraft; Archimedean screw (worm screw) vehicles, and mini-submersibles. Each, of course, has its strengths and weaknesses. Air-cushioned vehicles have been tested in the Arctic with some success. These vehicles can transit the ice-water continuum at considerable speeds with significant payloads. However, hovercraft are difficult to maneuver in high winds, are limited in their ability to negotiate pressure ridges, and ACV's are particularly vulnerable to skirt damage due to ice abrasion.

V/STOL aircraft, as well as hovercraft, have been evaluated for Arctic application. They offer the advantage over conventional fixed-wing aircraft of a limited take-off and landing area requirement while providing a generally larger payload capacity than conventional helicopters. However, as with other airborne carriers, V/STOL aircraft operations must be accommodated to the particular environmental conditions of the Arctic.

Archimedean screw vehicles are a relatively new development for polar regions, still in the developmental stage. Initial research indicates that these vehicles can operate effectively in the ice-water continuum; however, their speed does not approach that of other candidate vehicles. They may also be restricted in their ability to negotiate ice ridges. Though very limited in payload capacity, they are apparently very maneuverable and adaptable for towing and other utility functions.

Since they avoid ice and weather, mini-submersibles may be very attractive as all-weather logistic vehicles. Submersibles provide a capability for servicing sub-surface pipelines and other structures not present in other logistics vehicles. However, their safe operation requires extensive knowledge of the acoustic properties of the operating waters and good sounding data--two criteria not generally satisfied in polar waters. Moreover, operation of submersibles in ice-covered waters will present special problems in vehicle docking and emergency recovery.

Future Arctic marine logistic services will no doubt be provided by a range of vehicles. Research in this area should concentrate on development of new vehicles to overcome the limitations of conventional logistic vehicles. In particular research directed at eliminating or minimizing the shortcomings of the candidate vehicles discussed above could effectively increase the options available to future designers of logistics support systems for Arctic commercial and scientific ventures.

Marine Services for Transportation

Many studies have been conducted in the last few decades concerning resources of the polar regions. These studies identified significant quantities of valuable materials in the north polar region in the form of oil, gas, coal and ores that would be useful to the world at large if they could be extracted and transported outside the Polar area.

The worldwide shortage of oil and gas and, to a lesser degree, many other minerals has sparked a recent serious interest in the natural resources of the north polar regions. In the past, economics and severe environment have hampered commercial development of these resources, but today highly inflated costs from traditional sources make such a development economically attractive.

Extraction of Alaskan oil became economic in the last decade. As a result, many problems peculiar to Arctic operations were solved, a pipeline system was constructed, and is now delivering over one million barrels of oil per day to the lower forty-eight states. Natural gas in the Prudhoe Bay area has also reached an economic trade-off point and, it appears at this time, another pipeline will be added in the near term to handle this product. So, in the next few years, two products will be moving from two locations in the Arctic to locations outside.

An additional approach is needed if other Arctic resources are to be developed in the near to midterm future and added to the world supply of useful products. This is not to say that the pipeline approach is wrong or should not be further considered. Indeed, for those products that can be pumped (oil, gas, and coal slurries) the pipelines and marine transportation systems may complement one another or, in some cases, be in competition. For those products that cannot be pumped, the marine transportation system offers the only economically viable means of transportion.

Waterborne transport of bulk cargo in temperate regions is known to be the cheapest form of transportation today; for this reason it is natural that marine transportation systems be given serious consideration for use in the Arctic. A marine system, with due consideration for the extra costs resulting from the severe and unusual environment, may still enjoy an appreciable advantage over other systems.

Transportation Systems

The fundamental criterion on which any transportation system is judged is the unit cost of transporting cargo over the expected life

Transportation Systems

The fundamental criterion on which any transportation system is judged is the unit cost of transporting cargo over the expected life of the transportation system. Calculation of these costs involves numerous assumptions, each of which might be assigned a probability of accuracy or assigned a range of application. As an example, a proposed Arctic marine transportation system might consist of a fleet of large tankers that will have to transit many miles of ice covered waters. To compute the annual throughput of this fleet of tankers, one must be able to compute voyage times throughout the year. This will involve predicting speeds along each leg of the route, which in turn will require information on ice conditions and performance of the ship in ice. The latter information will involve assumptions that can greatly influence the unit cost of transporting the cargo.

The accuracy of the assumptions made in computing unit transportation cost depends heavily upon practical operating experience with the transportation system. The TAPS pipeline for example will provide valuable experience in computing the unit transportation cost of transporting oil and gas in Arctic regions by pipeline. Arctic marine transportation systems on the other hand do not currently enjoy similar operating experience. Costs associated with constructing and operating such a system could be perceived to be more risky than similar costs associated with a pipeline system. As a consequence, the unit transportation cost of an Arctic marine system would have to be substantially lower than that of a pipeline system to offset its associated risks.

Another important criterion for judging a transportation system is its potential effect on the physical environment. Factor & Grove (1979) describe the legislative requirements for environmental protection that had to be met before the TAPS pipeline could be constructed. They estimate that $3.2 billion of the $8.0 billion construction costs were a direct cost of delays caused by environmental litigation. In addition, they estimate that construction was delayed about four years by these claims and the Alaskan Native land claims. Only through a special act of Congress were permits finally granted for construction of the pipeline. The nature and extent of litigation regarding environmental protection requirements that would have ensued had an Arctic marine transportation system alternative been selected by the oil companies is unknown. However, from the environmental litigation surrounding the tanker operations into Valdez and Puget Sound, one might expect it would have been considerable. The greatest difficulty in applying environmental criteria to selection of a transportation system lies in quantifying environmental effects.

Marine Transportation System Advantages

Some of the marine system advantages, other than cost, that enhance its attractiveness are

3. A ship can move to a more temperate location for routine and periodic inspections, maintenance and overhauls, thereby decreasing the cost and inconvenience of these operations;
4. A marine transportation system would disturb the sensitive tundra, vegetation, and wildlife, less than some other systems;
5. The capacity of the system can be increased (or decreased) as needed by varying the number of ships used or the number of annual trips per vessel;
6. A marine system is the most practical way to provide life support to an enlarged population in the barren areas.

A marine transportation system for the Arctic comprises more than ships. At present, there are no deep-water terminals and few aids-to-navigation. Communication, search-and-rescue, and ship repair facilities are not adequate for full scale operations. The transportation system must, therefore, include a fleet of ships, an Arctic loading terminal, a southern offloading or trans-shipment terminal (unless existing facilities can be used), adequate navigation and communication facilities, and support facilities such as line-handling launches, tugboats, harbor or route icebreakers, etc. Major units in the system (ships and terminals) must be configured for the cargo to be handled, but the other units would be adaptable to any cargo.

The number of ships and configuration of terminals depend on the amount of cargo to be handled each year. Trip time for a surface ship in winter is five to six times longer than in summer. The number of ships is determined by dividing the expected annual total cargo movement by the cargo movement per ship, with appropriate allowance for weather, damage, delays, and maintenance. However, even if all scheduled out-of-service time occurs in the summer months, the frequency of ship arrival at the loading terminal will be greater in summer than in winter. Terminals in such circumstances will be designed to stockpile sufficient cargo by the seasonal start of shipping to accommodate faster-than-average ship loadings during the active period.

There are many special considerations in engineering a marine transportation system for such a severe environment as the Arctic. However, the state-of-the-art in icebreaking ship design is such that a marine transportation system can be produced to serve the Arctic region on a year-round basis. Consideration was given to the possibility of submarine bulk carriers in the Artic. Consensus was that the inherent inefficiencies of any such system effectively rules out this mode for the foreseeable future (20 year time frame of this study).

Marine Services for Resource Development

Up to this point, emphasis has been on transportation of Arctic resources to other areas. Another important consideration is offshore

Marine Services for Resource Development

Up to this point, emphasis has been on transportation of Arctic resources to other areas. Another important consideration is offshore marine structures, such as drill platforms for exploration and production, and various kinds of processing plants for preparation or reduction of the products for transport. As the frontier expands there will be a need for more and more of these structures and for life support systems, which will surely be largely marine oriented.

There is much common knowledge of the various marine structures associated with oil and gas exploration and production. The rigorous environment will require special attention in their design and material selection, and care must be taken in their movement, placement, and operation to prevent damage to the environment.

The growing need for various processing plants will expand as resources are developed. These plants include petroleum oil degassing and pre-treatment facilities to condition the oil for shipment, liquefaction facilities to convert petroleum gas to liquified natural gas or methanol, and processing facilities to refine ore into the desired minerals. Due to the severe environment and the lack of local facilities it is likely that such plants will be constructed and barge mounted away from the Arctic and then moved into place by marine systems. Their successful placement and operational support would be greatly enhanced by a year-round marine transportation system.

Marine Services for Life Support

As covered in detail elsewhere in this report the principal life support system for the relatively small and scattered population of certain areas in the Arctic is a marine transport system. Tug and barge combinations, operating primarily in the ice-free seasons, provide the required life support functions. It follows naturally that the present system must expand and be supplemented to accommodate an expanding and more widely scattered population as the resource motivated frontier moves out. A time will arrive when a seasonal supply system will be inadequate or, lacking a year-round system, exploitation of Arctic resources will reach a peak far short of full potential. Although supply requirements do not presently drive the need for a year-round maritime system, such a system could accelerate exploitation of the natural resources of the region.

Marine Services for Research

It was stated earlier that a marine system for scientific research is needed in the Antarctic although there appears to be no near term demand associated with resource exploitation. In the Arctic the requirements of basic scientific research are greatly argumented by impending applied research considerations. Arctic regions resource development has already commenced and maritime transportation plays its relevant role. The level of far northern commercial resource development is, however, relatively modest to date and limited in both range of commodities produced and location of activity.

Major research efforts will have to precede product diversification and geographical dispersion of Arctic resource utilization. Maritime services will be called upon increasingly to facilitate logistically such research. The resultant knowledge generated can, in turn, provide the data base essential to the alleviation of maritime transportation problems in high latitude settings.

Ice is a well known Arctic hazard. It impedes progress of a ship; it causes structural damage; it creates vibration when chunks hit the propeller blades; it creates shock loads when the ship must ram repeatedly; it creates high structural loads when it pinches the hull between two floes; it moves the ship off course when the entire ice sheet drifts; and it restricts the turning ability of the ship.

Sea ice can also affect fixed installations such as loading facilities or channel markers. Moving ice fields exert tremendous forces on any structure in their paths. The structure must be designed to resist those forces and to keep ice from flowing over or around the installation and interfering with its proper function.

More information is needed on all these problems and on the year-round characteristics of the ice itself. Design methods and ice information available today are so rudimentary that a naval architect must consciously overdesign to ensure an adequate factor of safety in service. This overdesign is a severe economic penalty.

A second Arctic hazard is the cold. In addition to causing low temperature embrittlement of many structural materials, and requiring special protection for exposed personnel and equipment, cold affects the design of things such as main condensers, insulation, heating and ventilation, etc. It also requires additional heating of tanks and piping to prevent freeze-up.

There are many other minor problems associated with operations in the Arctic. Among these are long nights and whiteouts that make visual operations impossible, inaccuracies of magnetic compasses, frequent interference with radio waves, and isolation from assistance in the event of trouble. Ways must be found to cope with these problems before Arctic shipping operations can become routine.

There is no better way to solve such problems than to live with them; move the research out of the laboratory to the field and feed the results back into the system. A marine transport system designed, engineered, and constructed in keeping with the best possible information available in the near future would constitute the most realistic research approach.

CONCLUSIONS

The Committee has concluded that:

1. Many resources are available in the Arctic that will utilize maritime services in the future as economic forces dictate their development. The clear immediate opportunity is for alternative transportation of oil and gas products. Living resources, although important, will not drive development of marine transportation systems. Requirements for fishing vessels, however, may increase.

2. Transportation technology is available for resource development, or can be developed when economic and institutional factors are favorable, if appropriate research and development programs are instituted to provide the necessary fundamental knowledge.

3. Economic and institutional constraints so far have made movement of Arctic resources by marine transport impractical. Although all of the problems of pipeline operation have not been solved, the pipeline now in use provides a baseline against which costs and risks of other transportation systems can be compared. No similar cost data are available for marine transportation systems. A pilot-project marine transportation system could develop the data and operational experience for a full scale system when needed and provide a partial back-up to the Trans-Alaska Pipeline System in the event of an interruption to its operation.

4. Arctic marine transportation development and associated industrial development will generate opportunities for the maritime industry. Opportunities may open for construction in U.S. shipyards not only of ships, but also of offshore drilling platforms and resource conversion plants to be transported to the Arctic.

5. While Antarctic resource development will be many years behind Arctic resource development, techniques perfected for the Arctic may be used in the Antarctic.

RECOMMENDATIONS

The Committee recommends that:

1. The nation's present energy problems and the availability of energy resources in the Arctic suggest that immediate development of Arctic marine transportation systems would be a prudent course of action. Development should be incremental. The first Arctic cargo system should be as simple as possible, using current technology and saving exotic approaches for later development. Research and development toward more advanced systems should be carried out in parallel with development of the basic system.

2. The first Arctic cargo transportation system should be a limited scale commercial marine transportation system for shipping crude oil from the Arctic. The first increments should be a single, small to medium size tanker with a corresponding local, minimal, terminal facility. The system should be financially sponsored, in the beginning, by the federal government, with substantial participation and ownership by private industry.

3. The recommended Arctic cargo transportation system should be designed to collect information on the advantages and disadvantages of marine transportation systems for the Arctic. Data should be collected on the nature of resources to be moved, on seasonal problems, and on land or water operations. Typical sets of economic and environmental variables that occur during operation will be the most realistic data base for creation of scenarios for operating conditions.

4. The Congress should direct appropriate agencies of the federal government to take long-range responsibility for Arctic weather and sea ice prediction services, collection of ice data, ice-breaker support, rescue capability, enforcement of regulations pertaining to Arctic operations, and fundamental research leading to development of marine transportation systems. To facilitate cooperation in maritime transportation research and development, a close and continuing relationship should be maintained with countries having interest in the Arctic. Development of Arctic marine systems should be coordinated, especially, with Canada and the State of Alaska to resolve environmental and indigenous population problems and rights of passage, all of which have economic and institutional ramifications.

5. Further study should be made of marine transport through the Northwest Passage to the East Coast of North America from Alaska.

6. U.S. shipyards, in cooperation with the Maritime Administration, should investigate opportunities for building offshore drilling platforms and conversion plants for use in the Arctic.

7. Continuous exchange of relevant research and operational information concerning Arctic marine transportation matters with other circumpolar nations, especially Canada, is strongly urged. Coordinated international research efforts can be mutually beneficial and cost efficient through the avoidance of unnecessary duplication.

APPENDIX A

MARITIME TRANSPORTATION RESEARCH BOARD
COMMITTEE ON MARITIME SERVICES TO SUPPORT POLAR RESOURCE DEVELOPMENT

INTERIM REPORT
ON

ANTARCTIC MARITIME SERVICE REQUIREMENTS

December 1979

INTRODUCTION

The study's objectives are:

- identify, to the extent possible, the polar areas and resources that may be commercially and strategically important in the 1980s and beyond and

- define marine transportation requirements for commercial, military, and scientific polar operations.

Arctic and Antarctic needs are to receive such emphasis as warranted by their potential for development in the time frame addressed in the report.

This interim report summarizes the committee's findings on the Antarctic. Potential marine transportation needs for the Southern Oceans examined by the committee were: support for scientific research, commercial development of both living and mineral resources, and tourism. Military needs were not examined because military measures are prohibited by treaty.

The final report will cover Arctic maritime service requirements in detail.

ANTARCTIC TREATY

The Antarctic Treaty of 1959, which has been in force since June 1961 and of which the United States is one of 13 Consultative Parties and original signatories, provides for only peaceful activities south of latitude 60° S. The treaty was conceived to provide a means for the nations that conducted extensive research in Antarctica during the International Geophysical Year (IGY) to continue their activities in the atmosphere of cooperation and freedom of access that prevailed during the IGY. The treaty deals with territorial claims and sovereignty, exchange of scientific personnel and information, prohibition of military activities other than logistic support of expeditions, a ban on nuclear explosions and nuclear waste disposal, and access and inspection by observers of all treaty nations of all stations, equipment, and installations in Antarctica.

Other provisions of the treaty protect Antarctic flora and fauna and designate specially protected areas. The treaty does not cover mineral resources, however.

In 1977, the treaty nations adopted a statement endorsing responsibility on the parts of the parties toward mineral resources, protecting the unique Antarctic environment and ecosystems, and preserving the interests of all mankind in Antarctica. The subject of mineral resources was placed on the agenda for the Tenth Consultative Meeting, scheduled for September 1979.

COMMERCIAL POTENTIAL

Minerals

No U.S. marine transportation needs for mineral resource development in Antarctic are presently seen.

A great variety of minerals has been found in Antarctica, but not in concentrations or accessbility that can be considered commercially exploitable. One sedimentary iron ore formation in the Prince Charles Mountains and one coal bed in the Transantarctic Mountains are large enough to be classified as deposits. Their inaccessibility makes them uneconomical for recovery. Discoveries of copper, chromium, gold, and other metals are so small in size or incompletely studied that they are termed occurrences.

Estimates of potential resources are statistical extrapolations of known resources on adjacent continents and the occurrences in Antarctica. A U.S. Geological Survey study, using these data, estimated that more than 900 major mineral deposits may be contained on the continent, but only about 20 are likely to be in ice-free areas.

Oil and gas appear to have the greatest economic potential of all Antarctic mineral resources, partly because they are more likely to be found offshore than under the continental ice. Estimates of 45 billion barrels of oil and 115 trillion cubic feet of natural gas have been made, but these are highly speculative extrapolations of worldwide average concentrations in sedimentary basins. Exploitation of either land or sea oil deposits would be costly, due to the harsh climate, drifting ice, and huge icebergs.

Although the physical difficulties and economics of mineral exploitation in the Antarctic suggest that commercial development is some time away, the subject will undoubtedly have high priority on the agendas of the Consultative Meetings of the treaty signatories.

Living Resources

U.S. fishermen have shown little interest in participating in Antarctic fisheries. No near-term needs for maritime support of U.S. commercial living resource development are foreseen.

Sealing was the first commercial enterprise in the Antarctic, starting in the late 1770s. Sealing was started by Britain and the United States, followed by Russia, France, and other European countries. Many of the islands within the Antarctic convergence were discovered by sealers searching for new seal rookeries. Uncontrolled slaughter decimated the fur seals so that by 1830 they were nearly extinct. After 1870 there was a revival of fur sealing when the herds began to recover, but the species was again brought near extinction within 10 years. The fur seal's numbers have since grown to about 200,000.

Soviet exploratory harvesting of crabeater seals in the early 1970s suggests a renewed interest in this resource. A revived sealing industry would be based on crabeater, leopard, and Weddell seals, rather than the elephant and fur seals that were nearly exterminated. It would also be regulated under the Convention for Conservation of Antarctic Seals.

Antarctic waters were the principal whaling areas for more than 50 years. Antarctic whale oil production exceeded that of all other whaling grounds combined, occasionally by as much as 10 to 1. The whaling fleet has dwindled from over 300 ships to a few dozen Japanese and Soviet vessels.

In 1946 delegates from the allied powers that had signed earlier whaling agreements produced an International Convention for the Regulation of Whaling, which is the present international law of whaling. The convention established the International Whaling Commission (IWC), which exercises oversight of the whaling industry.

In the late 1960s the IWC began to cut whaling quotas drastically. Japan and the USSR, which together have accounted for more than 80 percent of the world's whale harvest, vigorously opposed a move by the United Nations to adopt a 10 year moratorium on whaling. The IWC did not adopt the moratorium, but has set more stringent quotas. Neither Japan nor the USSR has protested the quotas since the 1973-74 season. On July 9-13, 1979, the IWC met and set a total moratorium on factory ship whaling for all species except minke. The entire Indian Ocean north of latitude 55°S was declared a sanctuary for all whales for the next 10 years.

These restrictions on whaling imposed by the IWC at this, its 31st meeting cast, serious doubts on the economic feasibility of whaling in Antarctic waters. The United States, being one of the conservationist members of the IWC, has done no whaling in the Antarctic for many years and none is foreseen.

Fish and Krill

Although the Southern Oceans produce large amounts of plankton, correspondingly large populations of fish have not been found. Less than 100 of the earth's 20,000 or so fish species have been identified south of the Antarctic convergence. Antarctic cod and southern blue whiting have been caught in commercial concentrations. Several species of toothfish and ice fish have been caught on an exploratory basis. Squid may appear in large numbers, but their commercial potential is unstudied.

During the 1970s, the Japanese and Soviets have been harvesting krill. Ships from Chile, Poland, Taiwan, and West Germany have recently conducted pilot projects in the krill fishery.

Krill were grazed upon by the baleen whales. Since the decline in whale numbers, there has been an apparent increase in other krill predators, particularly penguins and seals. The largest of the krill species, Euphasia Superba, has qualities suiting it for harvest: large concentrations, adequate individual size, and high protein content. Krill food products are marketed in both Japan and the Soviet Union. Krill harvesting and processing are, however, expensive and difficult. Krill must be processed within hours of being caught. The remoteness of the Southern Oceans from northern hemisphere markets, storms and hazardous navigation, preservation of the krill on the long return voyage, and mediocre consumer acceptance of krill have all inhibited the growth of the fisheries. Estimates of the amount of krill that can be harvested on a sustained basis vary from 30 million to 150 million tons per year. To provide more comprehensive data, a 10-year international Biological Investigation of Marine Antarctic Systems and Stocks (BIOMASS) is being undertaken by the Scientific Committee on Antarctic Research (SCAR) in cosponsorship with the Scientific Committee on Oceanic Research (SCOR), the International Association for Biological Oceanography (IABO), and the Advisory Committee on Marine Resources of FAO (ACMRR).

Tourism

There is no reasonable basis for predicting a U.S. maritime transportation requirement to support tourism in the Antarctic.

Tourism in the Antarctic is developing on a very limited scale. Lindblad Travel, of New York, has run vacation tours to the Antarctic. These tours go by air to Montevideo and then by a Singapore registered ship to Antarctica. Occasional charter flights from Australia have flown over the South Pole but have not landed on the Continent. The cost, the long voyage, and the forbidding climate of the Antarctic will certainly constrain all but a few tourists.

Science Support Requirements

The most important Antarctic maritime service requirement for the United States appears to be an ice- strengthened scientific research vessel. This is particularly needed for biological studies in and adjacent to the pack ice. The Polar Research Board and the Ocean Science Board of the National Research Council are discussing this requirement.

The International Geophysical year (IGY) conducted in 1957-58 was the first major scientific effort that involved Antarctica. The Antarctic was termed "a region of almost unparalleled interest," which included the influence of its huge ice mass on global weather and oceans as well as the nature of the aurora australis and of the ionosphere over the ice during the long total-night season.

Scientific research and its associated logistics are the major activities in Antarctica. The amount of research in Antarctica has not changed much in the past 10 years, but the research objectives and methods have. The major change has been from reconnaissance studies to investigations of natural phenomena and large-scale processes, with emphasis on long-term, interdisciplinary, and international programs, such as the Polar Experiment (POLEX), an international project started in 1975 and planned as a 10 year program. Polex-South will integrate and expand national programs on the atmosphere, oceans, and ice in the Antarctic. The basic objective of Polex is to gain a higher level of understanding of polar processes as an aid to explaining and predicting long term global processes.

There are currently 34 year-round stations in the Antarctic, of which the United States has four. McMurdo, the main U.S. base, is the largest multipurpose research and logistics center in Antarctica. Most of the 600 to 700 summer personnel operate the station's airfields and handle communications, weather forecasting, and maintenance and supply operations. The scale of McMurdo summer operations is the largest in Antarctica.

Marine research around Antarctica includes oceanographic, meteorologic, and biological observations. Most of the vessels used also provide logistics support to land research stations. Presently the U.S. operates HERO, a small motor-sailing vessel that operates in the Antarctic Peninsula area, a specialized oceanographic vessel, and Coast Guard icebreakers. Ships from the University-National Oceanographic Laboratory System (UNOLS) are available for open-water work, but none is ice-strengthened.

CONCLUSIONS

- There appears to be little incentive for U.S. commercial development of the Antarctic. No immediate marine transportation needs are foreseen for development of biological or mineral resources or for tourism.

- Transportation technologies for the Southern Oceans will be similar to those required for the Arctic because of the presence of pack ice and icebergs.

- Technology developed for Arctic marine transportation systems will mostly be transferable to the Antarctic should a requirement ever develop.

- An ice-strengthened scientific research vessel is needed to support the U.S. research programs in Antarctica, particularly for biological investigations in and near the pack ice.

Because there is no present need for commercial marine transportation systems in the Antarctic, emphasis in the Committee's final report will be on maritime services to support Arctic resource development.

APPENDIX B

Physical Environment of Bering, Chuckchi, and Beaufort Seas

Bering Sea

The Bering Sea is a large, relatively confined area of 2,300,000 square kilometers. It is an extension of the north Pacific Ocean, separated from the main water mass by the 2,000 kilometer Aleutian Island arc. The narrow Bering Strait connects the Bering Sea with the Chukchi Sea to the north. Most of this region is heavily influenced by seasonal ice cover.

Coastal physiography varies greatly. The Bering Sea is bounded on the south by the Alaska Peninsula and the Aleutian Chain. Passes between the Aleutian Islands (which vary in depth and size) allow movement of Pacific water northward. Shorelines of Alaska's coast vary widely. The northern shore of the Alaska Peninsula and Aleutian Islands has a predominantly gentle slope with wave-washed sand beaches and large, brackish lagoons along the Alaska Peninsula. The Pribilof Islands are characterized by steep cliffs and rocky shorelines.

Bristol Bay is a large, comparatively shallow bay in the southeastern Bering Sea, bordered by rugged mountains up to 1,500 meters elevation, lake-dotted tundra, and many rivers. The Nushagak and Kvichak Rivers are the major drainages into the bay. The coastline is relatively regular and marked by numerous sandy beaches. Older coastal deposits with some modern beaches, spits, and bars extend around the coastline and are prevalent on the Nushagak Peninsula and around Ugashik Bay. Some cliffs, ridges, and low hills bridge the bay between Cape Newenham and Kulukuk Bay. Low terrace and alluvial fan deposits occupy sites along the modern floodplains of lowland rivers, and many of the rivers have tidal estuaries. Shorelines of inner Bristol Bay are also low but of finer sediments. Westward to the Kuskokwim River Delta low shores and lagoons alternate with cliffs and high bluffs.

The Yukon-Kuskokwim Delta is the major river delta system of Alaska and is characterized by extensive meandering river channels and marshy ponds. Shorelines along Norton Sound and the Seward Peninsula are generally abrupt with steep bluffs and a few cliffs interspersed with small stretches of low-lying, sandy, or silty beaches.

St. Matthew Island can be characterized as a succession of hills and low valleys with a rocky coastline. The shore of St. Lawrence Island is characterized by low sandy beaches and grassy tundra with numerous freshwater lakes, and several large barrier island-lagoon complexes. These islands are of volcanic origin and rise abruptly from the Bering Sea platform.

The Continental Shelf, accounting for 44 percent of the total Bering Sea area, is one of the largest in the world and extends more than 600 kilometers offshore in the northeast sector. It is a flat, gently sloping plain with an average depth of less than 100 meters. Thirteen percent of the sea is Continental Slope incised by submarine canyons. To the west, the remaining 43 percent of the sea is ocean basin as deep as four thousand meters with a smooth, almost featureless floor, divided into two sub-basins by the Bowers Bank or Rat Island, submarine ridge. Near the Pribilof Islands the normal depths of the Continental Shelf are broken by numerous reefs and some islands. Shallow water extends offshore and rocky ledges protrude eight to ten kilometers to the northeast and west of the islands.

Bristol Bay has a surface area of over 150,000 square kilometers and is one of the most important salmon fishing grounds in the world. The bay is part of the large Continental Shelf, which is remarkably flat with minimal variation in relief. The average depth of the bay is 40 meters.

Norton Sound is a sub-Arctic embayment, averaging 20 meters deep. The sea floor of Norton Sound slopes gently downward to the west and at approximately 168° west longitude rises to form St. Lawrence Island. From here to Bering Strait the shelf remains relatively flat. Bering Strait has an irregular bottom with depths to 60 meters. Just south of the Strait the floor rises abruptly, forming cone-shaped island promontories--the Diomede Islands and Fairway Rock.

Characteristics of surface water entering the Bering Sea through Aleutian passes vary greatly during the ice-free season and are influenced by seasonal inflow from large, freshwater rivers and melting sea ice.

Surface circulation patterns divide Bristol Bay into a predominantly estuarine inner area and an outer bay with more oceanic character. The fundamental circulation pattern in outer Bristol Bay during ice-free months appears to be a simple counterclockwise gyre, driven by a combination of wind, tide, and estuarine effects. North Pacific waters enter the bay through the Aleutian Island passes, although the waters of the inner bay remain brackish.

Surface currents to the north reflect the general drift of surface water toward Bering Strait. Currents in Norton Sound are affected primarily by winds and freshwater from the Yukon River. Wind mixing may extend to the bottom of the Sound and may drive significant currents. Surface waters flow northward past the west end of Norton Sound and a deep influx of Bering Sea water flows inward along the bottom of the Sound.

Surface currents in the adjacent northern Bering Sea are relatively complex, but the general set is northerly. During summer two major currents predominate, a north-flowing current along

Alaska's coast and a south-flowing current along the Siberian coast. A major system of eddies occurs between these currents. In winter a similar regime prevails, but some deflection of the water flow occurs at the pack ice edge, where surface currents tend to shift westward. Current velocities average one knot in the northern Bering Sea and increase in velocity as they converge near the geographic constriction of Bering Strait.

Tides are mixed in the Bering Sea with small mean ranges, generally nine-tenths to one and a half meters. Tides cause some coastal ice scouring and influence water movements in Norton Sound. Tidal currents vary from one half to one and seven-tenth knots, but in Norton Sound may reach two knots. Here tidal current direction changes from east to west with flood or ebb, respectively.

The mean range of diurnal tides in the western and central Aleutians is one meter. Mixed tides occur along the Alaska Peninsula with a range of one to one and a half meters. Amplification of the tide toward the head of Bristol Bay occurs due to the funnel-shaped configuration of the bay. The mean range varies from six-tenths to five and six tenth meters. Tides exhibit large inequalities in heights and durations of successive high and low waters. Tidal currents in eastern Bristol Bay often reach six knots and have an important influence on water movement and winter ice conditions. Storm tides occasionally cause widespread coastal flooding in the Yukon and Kuskokwim River delta areas.

Influx of sediments into Norton Sound and the northern Bering Sea results primarily from river runoff, particularly from the Yukon and Kuskokwim Rivers. The Yukon contributes 90 percent of the total river sediment in the entire Bering Sea, amounting to about 100 million metric tons per year. Rivers carry sediments scoured from banks or drained from adjacent land surfaces and generally deposit them near the river mouths. The tremendous deltas of the Yukon and Kuskokwim Rivers are impressive examples of sediment deposition. Reworking of shallow marine bottom sediments by wind mixing and current action is also important to the sediment regime in this region, since resuspended materials are often transported and distributed into adjacent areas. Waves formed along the north shore of Norton Sound during severe storms probably roil sediments extensively and mass movements of sediments occurs during these episodes.

Sediments from rivers draining the Alaska Peninsula and Bristol Bay uplands accumulate rapidly in the Bering Sea. Near-shore areas are covered with sand, silt-sized particles become more predominant toward the Continental Slope, and clayey oozes occur in the deep ocean basins.

Chukchi Sea

The Chukchi Sea is a shallow body of water lying between the Arctic Ocean and Bering Strait. Its western boundary is near Wrangell Island, USSR at 180 degrees west longitude while the eastern boundary lies at 156 degrees west longitude at Point Barrow, Alaska. The Alaska and Siberian coasts border the Chukchi south to Bering Strait.

The Chukchi Sea averages 45 to 55 meters in depth, and the bottom is a flat, featureless plain connecting Alaska's landmass to the Siberian landmass. The sea floor slopes gently, ranging from three meters per kilometer to nearly unmeasurable slopes. The surface of the shelf is affected in most areas by dragging sea ice chunks and keels of pressure ridges, especially near shore. Characteristic of Alaska's low-lying Chukchi Sea coast, is a somewhat broken, beadlike, series of lagoons from Cape Prince of Wales to Point Barrow. The environment of the lagoons is estuarine during summer, subject to freshwater influx from land and mixing with marine water from nearshore areas. The onshore region is low and marshy with numerous lakes and small streams and is underlain by discontinuous thin to moderately thick continuous permafrost.

Kotzebue Sound, from Cape Espenberg to Cape Krusenstern, is a shallow, sediment-filled embayment with no natural harbor. The Kobuk and Noatak Rivers empty into the sound, contributing the major portion of its sediments and reducing its salinity to ranges from 16 to 31 parts per thousand. The floor in the sound is very flat, with depths averaging 12 to 14 meters. The entrance to the sound is cut by a channel between Cape Krusenstern and Cape Espenberg which trends northwestward toward the submarine head of Hope Sea Valley in the northcentral Chukchi Basin and becomes indistinct west of Cape Krusenstern.

Sediment-laden waters from the Yukon River flow into the Chukchi Sea through Bering Strait. This north-flowing current provides most of the sediment found in the Chukchi basin. Wave erosion of shoreline cliffs, ice rafting, and wind action also contribute sediments.

Beaufort Sea

The Beaufort Sea, part of the Arctic Ocean, has a narrow Continental Shelf that extends 48 to 96 kilometers off the northern coast of Alaska, where depths are less than 200 meters. The water mass is greatly influenced by circulation patterns of the Arctic Ocean. The onshore region is characterized by flat lowlands of the arctic coastal plain, dotted with numerous marshes and thaw lakes. The Colville, Kuparuk, Sagavanirktok, and Canning Rivers carry sediments that combine with those eroded from coastal banks, are distributed by local longshore currents, and are formed into beaches and offshore barrier islands by wave action. Some evidence suggests that offshore islands and barriers are in part, tundra remnants. The barrier islands are the distinctive feature of this coast. Estuarine-type waters (generally less than three fathoms deep) exist between the islands and mainland.

The surface of the continental shelf is affected by dragging ice blocks. Large chunks of floating sea ice, occasional pieces of broken ice islands, and deep keels of pressure ridges become grounded in shelf sediments and form deep gouges in the sea floor. Ice gouges have been found as far out as the edge of the continental shelf, although they are more numerous in shallower waters, especially along the ice shear zone.

APPENDIX C

SUBARTIC AND ARCTIC TIDES[1]

Bering Sea

The semidiurnal tidal wave of the Bering Sea, emanating from amphidromic regions in the northeast and midequatorial Pacific, approaches from the southeast. On entering the Sea through the passes (principally Unimak, Amukta, and Amchitka) of the Aleutian Islands, the wave refracts markedly to traverse the Sea from south to north; the transit to Bering Strait taking about four tidal hours. The diurnal tidal effect, emanating from the midequatorial Pacific amphidromic region, enters and refracts as the semidiurnal does. However, its transit time is about 20 hours.

On the Siberian side, the mean range varies from about 1.2 m to 15 cm (4 ft to 0.5 ft) from south to north with the spring range being about 15 cm (0.5 ft) greater. From Bristol Bay to Seward Peninsula, the range decreases from about 4.5 m (15 ft) [6 m (20 ft) spring] to 30 cm (1 ft) [46 cm (1.5 feet) spring]. A slight increase from about 61 cm (2 ft) to 91 cm (3 ft) occurs in a westerly direction out the Aleutian chain.

The tide of the Bering Sea can be characterized as being highly mixed with predominantly diurnal conditions on the outer Aleutians and in the eastern portions of Norton Sound.

Chukchi Sea

The semidiurnal tidal wave enters the Arctic Ocean via the Greenland Sea; apparently radiating out into the Barents Sea, north Siberian shelf, northern Canada, and the Beaufort and Chukchi Seas. Thus, in most areas of the Arctic, the tide approaches from the north.

The mean range decreases from 46 cm (1.5 ft) at Wrangell Island [61 cm (2.1 ft) spring] east to less than 15 cm (0.5 ft) at Pt. Barrow and down to Bering Strait. However, due to reflection, the mean tidal range is 61 cm (2.1 ft) [82 cm (2.7 feet) spring] in Kotzebue Sound.

Beaufort Sea

The mean range is 9 cm (0.3 ft) [12 cm (0.4 ft) spring] at Pt. Barrow. These ranges increase progressively across Alaska and into Canada to a value of 34 cm (1.1 ft) (mean) [37 cm (1.2 ft) spring] at Tuktoyaktuk, Mackenzie Bay.

Northern Canada

The myriads of islands comprising the Canadian Arctic; together with the innumerable interconnecting straits, sounds, channels, inlets, gulfs, bays, etc., defy a simple, logical description. This is because the basic tidal wave, generally approaching from the north, itneracts in phase and height relationships as it propagates (and interferes from the differing directions) through the waterways. The reader, therefore, is encouraged to consult the specific data in Table C-1, the "Tide Tables East Coast of North and South America Including Greenland (annual)," and appropriate charts and maps.

In describing the range variation, one can proceed from west to east at latitude 74°N traversing M'Clure Strait, Viscount Melville Sound, and Barrow Strait to Lancaster Sound. The mean range in such a traverse is 49 cm (1.6 ft) on Banks Island, 76 cm (2.5 ft) on Melville, 85 cm (2.8 ft) on Byam Marin, 91 cm (3.0 ft) on Griffith, and 1.4 m (4.6 ft) on Prince Leopold Island. The equivalent progressive increases in spring range values are 61 (2.0), 98 (3.2), 112 (3.7), 119 (3.9), and 180 cm (5.9 ft), respectively.

North, in the Queen Elizabeth Islands, representative mean range values are 46 cm (1.5 ft) [58 cm (1.9 ft) spring] at Penny Strait, 24 cm (0.8 ft) [34 cm (1.1. ft) spring] at Cape Columbia, Ellesmere Island, and 49 cm (1.6 ft) [67 cm (2.2 ft) spring] at Alert, Cape Sheridan, Ellesmere Island. South, is 70 cm (2.3 ft) [91 cm (3.0 ft) spring] in Prince of Wales Strait and the ranges through the Northwest Passage and in Hudson Bay, which follow.

Northwest Passage

The Passage (east to west), beginning where Lancaster Sound leaves Baffin Bay, is conspicuously devoid of tidal information. At Port Leopold, where Prince Regent Inlet carries the Passage south, the mean range is 1.4 m (4.6 ft) [1.8 m (5.9 ft) spring]. Halfway down the Inlet, the mean range is somewhat decreased to 3.5 feet (4.5 feet spring). In Ballot Strait, a short east-west jog, the mean range is 1.1 m (3.5 ft) [1.4 m (4.5 ft) spring].

No tidal information exists for Franklin Strait, James Ross Strait, Rae Strait, Rasmussen Basin, Simpson Strait, or Queen Maud Gulf.

At Cambridge Bay, Dease Strait, the mean range is 30 cm (1.0 ft) [40 cm (1.3 ft) spring]. No further tidal information exists for Coronation Gulf, Dolphin and Union Strait, or Amundsen Gulf. The latter joins the Beaufort Sea (see above).

Hudson Bay

Although a tidal body in itself, the contribution of the tidal wave entering from Hudson Strait with a 7m (22.8 ft) mean range [9.4 m (30.9 ft) spring] is significant, to say the least. However, it is quickly damped on entering the Bay between Southampton Island and Quebec. Along the east side of Hudson Bay, the mean range decreases from 3 m (10.4 ft) [4.3 m (14.0 ft) spring] to 1.3 m (4.3 ft) [1.6 m (5.3 ft) spring] in James Bay. On the west side the mean range increases from 2.4 m (7.9 ft) [3.1 m (10.3 ft) spring] on Southampton Island to 3.3 m (10.7 ft) [4.1 m (13.4 ft) spring] at Churchill and then decreases to 1.2 m (4.0 ft) [1.6 m (5.4 ft) spring] at the head of the Moose River.

Barents Sea

The tide enters the Arctic via the Norwegian and Greenland Seas. Refraction propagates the tide into the Barents Sea from the Norwegian Sea between Spitsburgen and Norway. The wave refracts still further, such that it approaches Siberia from the north.

Bear Island, at the entrance, records a mean range of 73 m (2.4 ft) [98 cm (3.2 ft) spring]. Proceeding clockwise, a mean range of 30 cm (1.0 ft) [37 cm (1.2 ft) spring] is on Franz Josef Land, 43 cm (1.4 ft) [55 cm (1.8 ft) spring] on the northeast cape of Novaya Zemlya, 64 cm (2.1 ft) [79 cm (2.6 ft) spring] on southwest Novaya Zemlya, 2 m (6.6 ft) [2.5 m (8.3 ft) spring] at Cape Kanin, Siberia, and 2.4 m (7.9 ft) [3 m (9.9 ft) spring] at Murmansk.

NOTE

1 The material in Appendix C and Table C-1 is from the National Oceanographic and Atmospheric Administration.

TABLE C-1

Representative Tidal Ranges

	Range (feet)	
	Mean	Diurnal
Bering Sea		
Dutch Harbor	2.2	3.7
Inanudak Bay, Umnak Is.	2.2	3.7
Nazan Bay		3.3
Sweeper Cove, Adak Is.		3.7
Massacre Bay, Attu Is.		3.3
Nushagak Bay, Bristol Bay, AK	15.3	19.5
Village Cove, St. Paul Is.	2.0	3.2
St. Matthew Is.	1.3	2.1
Fossil R., St. Lawrence Is.	1.3	1.7
Kawanak Pass, Yukon Riv.	1.5	2.7
St. Michael, Norton Sound		3.9
Nome	1.0	1.6
Port Clearence	1.2	1.4
	Mean	Spring
Plover Providenlya	2.3	2.9
Strelka Spit, Anadyr Gulf	2.7	3.6
Ugolnaye Bay	1.3	1.7
Cape Olyutorski	3.8	4.5
Chukchi Sea		
Cape Billings	0.5	0.8
Wrangell Is.	1.5	2.1
Cape Uelen	0.4	0.5
	Mean	Diurnal
Kiwalik, Kotzebue Sound	2.1	2.7
Beaufort Sea		
Pt. Barrow	0.3	0.4
Flaxman Is.	0.5	0.7
Herschel Is., Mackenzie Bay	0.6	0.7
Tuktoyaktuk, Mackenzie Bay	1.1	1.2
	Mean	Spring
Northern Canada		
Princess Royal Is.	2.3	3.0
Mercy Bay, Banks Is.	1.6	2.0
Winter Harbour, Melville Is.	2.5	3.2
	Range (feet)	
	Mean	Spring
Northern Canada (continued)		
Byam Martin Is.	2.8	3.7
Igloolik	4.6	6.0
Hall Beach, Foxe Basin	1.7	2.0
Beechy Is., Barrow Str.	4.9	6.4
Griffith Is., Barrow Str.	3.0	3.9
Penny Str.	1.5	1.9
Cape Columbia	0.8	1.1
Alert, Cape Sheridan	1.6	2.2
Northwest Passage		
Cambridge Bay, Dease Str.	1.0	1.3
Port Kennedy, Bellot Str.	3.5	4.5
Port Bowen, Pr. Reg. Inlet	3.4	4.5
Port Leopold, Pr. Reg. Inlet	4.6	5.9
Hudson Bay		
Big Is., Hudson Str.	22.8	30.9
Coral Harbour, Southampton Is.	7.9	10.3
Chesterfield Inlet	9.2	11.8
Churchill	10.7	13.4
Moose Factory, James Bay	4.0	5.4
Charlton Is., James Bay	4.3	5.3
Digges Harbour	7.1	9.3
Nottingham Is.	10.4	14.0
Greenland Sea		
Cape Morris Jesup	0.4	0.6
Danmarks Havn	3.6	4.7
Myggbukta, Foster Bay	3.4	4.4
Danmarks Is., Scoresby Sound	2.4	3.3
Mary Muss Bay, Jan Mayen Is.	2.8	3.7
Hrisey	3.0	3.8
Barents Sea		
Bazarnaya Bay	7.3	9.2
Yekaterininskaya	7.9	9.9
Cape Zhelaniya	1.4	1.8
Cape Kanin	6.6	8.3
Pukhovy Bay, Novaya Zemlya	2.1	2.6
Cape Zhelaniya, Novaya Zemlya	1.4	1.8
Cape Flora, Franz Josef Land	1.0	1.2
Bear Is.	2.4	3.2

APPENDIX D

SCENARIOS FOR ICE TRANSITS THROUGH WESTERN HEMISPHERIC WATERS FROM THE BERING SEA EAST TO THE BARENTS SEA

SCENARIO I: Deep Draft, Optimum Conditions (Fig. D-1)

During this transit, ice free conditions should prevail until the vessel is near Point Barrow.

Upon clearing the Unimak Pass on a northnorthwesterly heading, the Master of "MANHATTAN II" proceeds west of St. Lawrence Island as advised by "Ice Central." This decision is based on expected near storm force southeasterly winds, which would lower water depths somewhat east of St. Lawrence Island and would expose MANHATTAN II's beam to wind and sea. Bathymetric constraints east of St. Lawrence Island would add further risk to this passage. In spite of wind and sea, MANHATTAN II makes the passage from Unimak Pass to the Bering Strait in 48 hours with a speed of advance (SOA) of approximately 18 knots. From the Bering Strait, MANHATTAN II proceeds to Cape Lisburne and then coastal to Pt. Barrow. remaining seaward of the 15 fathom curve and reaching Pt. Barrow in about 24 hours with a SOA of 20 knots. After clearing the Bering Strait, wind and sea subside and optimum conditions prevail. In the Barrow vicinity, approximately one tenth ice coverage is encountered. This ice consists largely of remnant pressure ridges.

The master and other key command personnel visit the ice observer/forecaster team at Barrow and are given a personal briefing. The master comments on the voice radio and facsimile reception, which has been excellent. The ice team advises the master that during the transit from Pt. Barrow to the open water area off the Mackenzie Delta he will encounter heavy fog for at least 72 hours and encounter seven to nine tenths coverage of mostly old ice between 150 degrees west and Barter Island. The master is also advised that an icebreaker, conducting oceanographic surveys is available in the area between 150 degrees west and Barter Island to render assistance if needed. The ice pack in the area immediately seaward of the 15 fathom curve, although heavily puddled, has few thaw holes. Further, the floes are mostly 300 feet or greater across the major axis and are heavily ridged, having a maximum vertical thickness of 80 feet. No shelf ice fragments are predicted along the recommended track. No significant change is expected in the current sea ice condition.

MANHATTAN II proceeds east of Pt. Barrow, remaining seaward of the 15 fathom curve in open water, but ice coverage gradually increases to

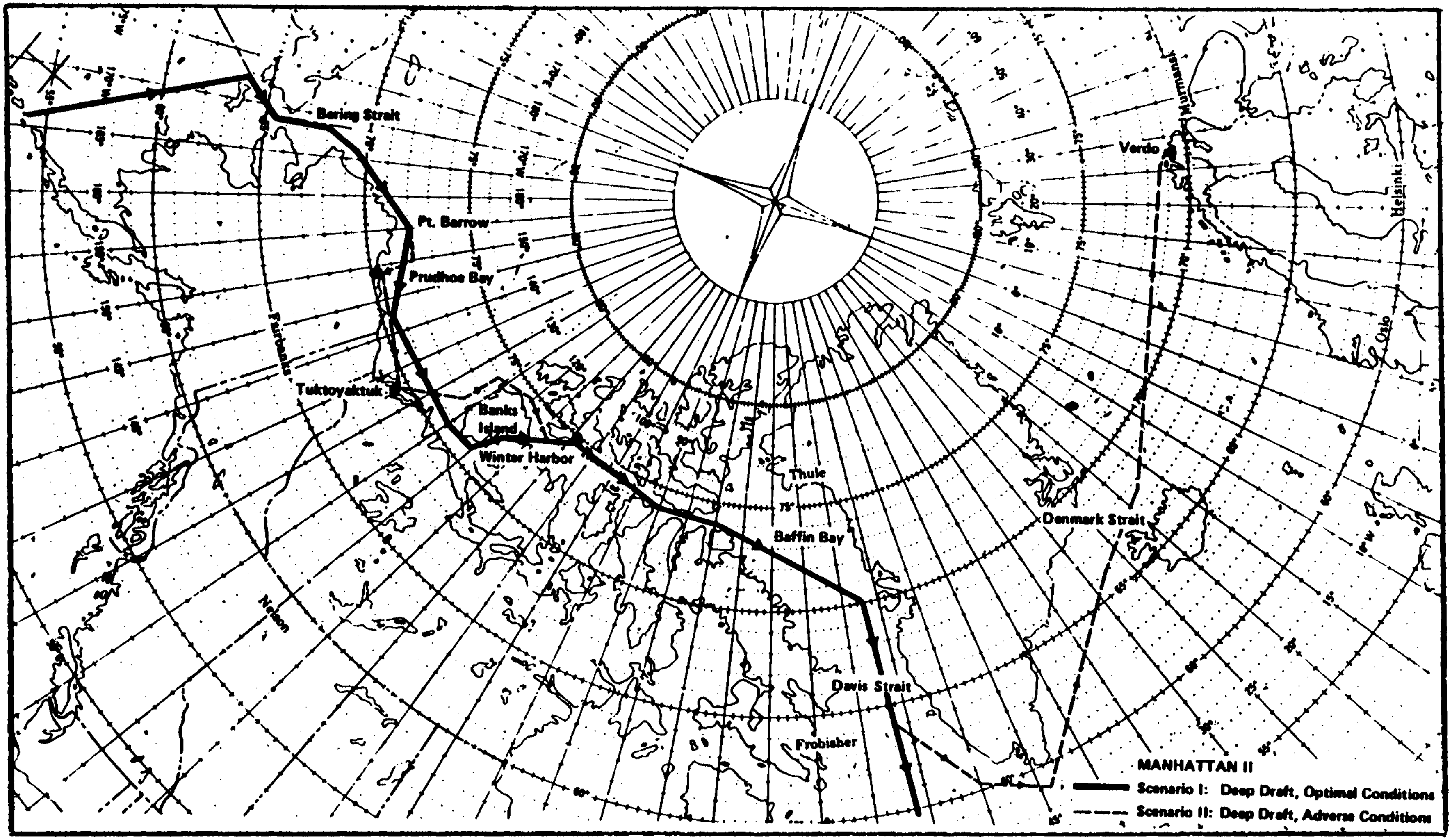

FIGURE D-1 Voyage of MANHATTEN II

7 tenths at 150 degrees west. Fog, rather then sea ice concentration, reduces the SOA to 5 knots so that 150 degrees west is reached in 24 hours. At this point, although the ice concentration is greater, the fog has thinned and MANHATTAN II proceeds at 10 knots to a position 24 nautical miles (NM) north of Barter Island. When MANHATTAN II reaches 150 degrees west (40 NM north of Oliktok) an ice reconnaissance aircraft provides information on ice conditions for transit to the Barter Island vicinity. Transit of this portion of the track takes 14 hours. As expected, ice concentrations are less severe east of Barter Island and the route becomes ice free at 140W. MANHATTAN II heads for the entrance to Prince of Wales Strait increasing speed to maintain 22 knots. This portion of the transit takes 21 hours. MANHATTAN II has been underway 131 hours, or nearly 5.5 days since clearing Unimak Pass.

Ice Central advises that Prince of Wales Strait is ice free to open water until reaching the northern extremity. From this point to 60 NM southwest of Winter Harbour, Melville Island, where supplies and equipment will be offloaded and natural gas taken aboard: coverage in excess of eight tenths of mostly old ice is expected. A few weathered ridges are predicted. Prince of Wales Strait is transited in 10 hours at an average SOA of 20 kts. Upon reaching Viscount Mellville Sound and heavier ice, the SOA is reduced to 8 kts. A support icebreaker has broken a channel across the Sound through a path of least resistance determined by aerial ice reconnaissance. From Viscount Melville Sound to Winter Harbour and docking takes 21 hours.

MANHATTAN II reaches Winter Harbour from Unimak Pass in 162 hours or 6.75 days.

Offloading and loading takes 4 days and MANHATTAN II is underway for the east coast of the United States. Recommended routing through the remainder of Viscount Mellville Sound and Barrow Strait to open water in Lancaster Sound is by tracking along the north side of the Parry Channel where light ice conditions are expected. From Winter Harbour to Barrow Strait there is a narrow shore lead in otherwise uniform old ice now melted to a thickness of about three feet. The shore lead itself has ice coverage of mostly one to three tenths with patches of five to six tenths, which slows the SOA to an average of 10 kts until clearing Barrow Strait, where open water is encountered. From Barrow Strait to the eastern entrance of Lancaster Sound the SOA is increased to 15 knots and the track from Winter Harbor to Baffin Bay is accomplished in 38 hours, or 1.6 days. When MANHATTAN II enters Baffin Bay, the total time underway has been 200 hours or 8.3 days plus the loading and offloading time at Winter Harbour.

Baffin Bay as far south as the Davis Strait is largely ice free. The ice reconnaissance aircraft and satellites, however, have been carefully monitoring remnants of old ice floes drifting south from Nares Passage (between Greenland and Ellesmere Island) as well as individual icebergs and iceberg clusters. A recommended track, circumventing these and taking into account their movement is presented to MANHATTAN II from Ice Central via communications satellite. MANHATTAN II makes good 20 knots and arrives at a position midway between Baffin Island and Greenland at 65 degrees north in 36 hours or 1.5 days.

MANHATTAN II is now in ice free waters except for widely scattered icebergs and can proceed south to east coast ports at speed depending on visibility. She has reached this point in 236 hours or 9.8 days plus loading and offloading time. The same ice free conditions exist south of Greenland, through the Denmark Straits to the Barents Sea. However, there are icebergs along this track until reaching a position east of 10 degrees west. To ensure that no icebergs or fragments thereof will interfere with the track, careful account was again taken of aerial reconnaissance reports and satellite analyses. In addition, the wind and sea condition forecast for this historically heavy weather area is for relatively favorable conditions. Thus, maximum speed is again feasible and **MANHATTAN** II enters the Barents Sea, at 73N and 20E, 98.6 hours or 4.1 days from Winter Harbor. Therefore, from the Unimak Pass to the entrance to the Barents took 334.6 hours or 13.9 days plus offloading and loading time of 4 days.

SCENARIO II: Deep draft, most adverse conditions (early spring) (Fig. D-1)

MANHATTAN II, after a rough crossing of the Gulf of Alaska, proceeds through the Unimak Pass and takes a heading for the west of St. Lawrence Island. Preliminary advice from Ice Central states that pack ice will be encountered near 56 degrees north. Central also advises that light to moderate, east to west pressure will be encountered until the vessel is north of St. Lawrence Island, there will be a large refreezing polynya, an area of open water, south of St. Lawrence to near 61 deg. north, and an ice bridge between the northwest tip of St. Lawrence (Gambell) and Cape Chaplina, Siberia. Finally, Ice Central advises that extremely rough ice exists along the north coast of St. Lawrence Island. The master of **MANHATTAN** II had earlier received the projected ice thickness for the Bering Sea. Thickness increases gradually from 1 to 2 feet near the ice edge to four feet near the Bering Strait in this wholly first-year ice. Ridges, too, will increase in overall thickness from south to north, but will be usually about 20 to 30 feet thick south of St. Lawrence and 30 to 50 feet thick north of St. Lawrence. Except for extremely rough ice along the north coast of St. Lawrence Island, the maximum ridge sail/keel thickness should not exceed 90 feet, and such ridges would be rare.

MANHATTAN II makes 22 knots to the ice edge where the SOA is slowed to 12 kts and the ice bridge west of St. Lawrence Island is reached in 49.2 hours, or 2.05 days. From the ice bridge to the Bering Strait, consolidated ice slows the SOA to 8 kts, and the Strait is reached in 16.25 hours. **MANHATTAN** II has reached Bering Strait from Unimak Pass in 65.45 hours, or 2.73 days. An ice reconnaissance aircraft reconnoitering the track from Bering Strait to Pt. Barrow establishes voice contact and verifies the earlier prediction by Ice Central that parallel bands of east-west ridges lie across the track from 66°30' north to 69°30' north. The laser profilometer aboard the aircraft established the average sail height of these ridge bands to be 11 to 12 feet. With a sail to keel ratio between 1:4 and 1:5, the overall thickness of the ridges should be from 55 to 72 feet. The reconnaissance aircraft also reports that the ridge heights are somewhat lower and less continuous along 169 degrees west and that the thickness of the relatively level ice is about 4 to 4.5 feet. The master decides to transit the ridges by deviating slightly to the west of the original track. He also decides to utilize a "saw tooth" approach to individual bands, thereby increasing the distance between bands, which will permit the vessel to gain momentum prior to encountering each successive ridge line. This approach proves successful and MANHATTAN II makes good 4 knots until it is past Cape Lisburne. The time from Bering Strait is 65 hours, or 2.7 days. The same strong winds that were responsible for the parallel bands of ridges have opened a wide but refreezing flaw lead from Cape Lisburne to Icy Cape, where it starts to narrow. This flaw lead was predicted to persist all the way to Pt. Barrow, and MANHATTAN II, still seaward of the 15 fathom curve, and in ice only 8 inches thick, increases its SOA to 18 knots, arriving off Barrow, Alaska in 13.33 hours, or .5 days from Cape Lisburne. MANHATTAN II has reached Barrow from Unimak Pass in 6 days. Ice Central recommends holding at Barrow for 36 hours to allow a migratory high pressure cell with attendant strong northerly winds to track across the Beaufort Sea into the Canadian islands. MANHATTAN II is expected to take advantage of the light southerly circulation on the western side of this high cell on the Beaufort Sea portions of the transit. This will relieve the extant pressure. In the meantime, the MANHATTAN's master visits the ice team at Barrow for a detailed briefing and to resolve some slight air to ship communications problems. MANHATTAN II delays another 12 hours to take advantage of the latest aerial reconnaissance and the incoming 5 day forecast from the ice center. Underway again with considerably improved conditions, MANHATTAN II proceeds to Prudhoe Bay, where tests will be conducted on the ability of deep draft vessels, super tankers, or LNG ships to berth and take on liquid cargo at the offshore terminal being constructed in the vicinity of the old west dock. On this leg of the transit MANHATTAN II takes advantage of a predicted intermittent flaw lead on track, generally along the 15 fathom curve. First-year sea ice covers the track with old ice increasing to eastward, but generally less than three tenths coverage. The old pack ice lies some 30 to 40 NM to north of track. The first-year ice is generally 5.5 to 6 feet thick and the old ice is about 10 feet thick. Frequent pressure ridges are expected; random in orientation and generally up to 50 feet in overall thickness, a few will exceed 100 feet in overall thickness. A shear zone of extremely thick and nearly continuous ridges lies south of the track, approximately along and south of the 10 fathom curve. The master is advised by aerial reconnaissance that an unusually massive ridge has developed across the track at 150° west. This ridge is partially grounded, and can be avoided by a track deviation to the north. Proceeding prudently, along the recommended routing, MANHATTAN II arrives at the Prudhoe Bay offshore terminal in 60 hours from Barrow with an average SOA of about

5 knots. With the delay at Barrow awaiting more favorable conditions, MANHATTAN II reaches Prudhoe Bay from Unimak Pass in 10.49 days.

The master is advised by Ice Central that along the track from Prudhoe Bay to Tuktoyaktuk, where additional terminal capability tests will be conducted, the ice will be more severe than normal from Prudhoe to the vicinity of Herschel Island, but will improve considerably from there to 132° west, and would improve dramatically for the remainder of the leg to Tuktoyaktuk. A Canadian icebreaker conducting winter tests in the vicinity of the quasi-permanent Bathurst polynya is available for assistance if required. Ice in the severe area is mostly old ice with frequent, deeper draft ridges than previously encountered. MANHATTAN II departs Prudhoe Bay after successfully completing three days of testing. Still following the west side of the high pressure cell, MANHATTAN II encounters no ongoing ice pressure and is able to make good about 2 knots SOA through the severe area. The Herschel Island vicinity is reached in about 50 hours, or 2.1 days from Prudhoe Bay. At this time MANHATTAN II gradually increases speed as ice conditions become more favorable and reaches Tuktoyaktuk in 30 hours, or 1.25 days. MANHATTAN II reaches Tuktoyaktuk in 16.8 days from Unimak Pass including the various delays enroute. Ice encountered from Herschel Island eastward is first-year with a thickness of 5 to 6 feet; ridges, although less deep drafted, are frequent and randomly oriented. While MANHATTAN II conducts tests at Tuktoyaktuk, a reconnaissance aircraft records ice conditions through both the Prince of Wales Strait and west of Banks Island through M'Clure Strait. This reconnaissance information and the predicted circulation from Ice Central, prompts a telephone call from the master to the ice center. It is decided to route MANHATTAN II west of Banks Island through M'Clure Strait and then to Winter Harbour, Melville Island via the north side of Viscount Melville Sound. The rationale for this decision is the existence of and the prediction for continuance of the Bathurst polynya and a wide flaw lead west of Banks Island that extends well into M'Clure Strait. Only 6 to 8 inches of ice are expected in the polynya and the flaw lead, whereas, when reaching inner M'Clure Strait, winter ice with a thickness of 7 feet and old ice with a thickness of 10 to 12 feet will be encountered. In this case, as well as historically, the north side of M'Clure Strait and Viscount Melville Sound experiences somewhat less thick ice than the center or the south side. Taking advantage of the predicted, and indeed experienced, new ice in the polynya and the flaw lead, MANHATTAN II after three days of testing at Tuktoyaktuk is underway for Winter Harbour at 18 knots. Reaching the thicker ice inner M'Clure Strait in 22.2 hours, MANHATTAN II then proceeds to Winter Harbour at a markedly reduced SOA averaging 3 knots. Winter Harbour is reached in 80 hours or 3.3 days. The voyage so far has taken 24.1 days from Unimak Pass.

While MANHATTAN II is offloading and loading at Winter Harbour (five days), aerial reconnaissance to the east reveals that the ice in the eastern section of Barrow Strait and Lancaster Sound is relatively thin first-year ice about 2 to 2.5 feet in thickness with only an occasional old ice floe and widely scattered small icebergs, generally clustered near the north side of the Sound at the eastern entrance. Information received at Ice Central from long range reconnaissance conducted from Thule Air Force Base, Greenland, and verified by satellite indicates that the southern portion of Davis Strait is ice free and except for a 60 NM wide band of ice adjacent to the west and south coast of Greenland, the east side of the Laborador Sea is ice free. Also, the east side of Baffin Bay has much thinner ice than the west side. Based on this reconnaissance information, predictions and recommendations, the master proposes to exit Lancaster Sound on an eastsoutheasterly heading, cross to the east side of Baffin Bay then proceed south and southsoutheast to the southern point of Greenland (Cape Farewell) remaining approximately 70 NM off the coast. Until reaching the east side of Barrow Strait, MANHATTAN II can expect similar conditions to those in Viscount Mellville Sound. MANHATTAN II clears Barrow Strait with a SOA of 3 kts in 70 hours where speed is increased to 16 knots and the eastern entrance of Lancaster Sound is reached in 15 hours. From this point and with an eastsoutheast heading, MANHATTAN II encounters mostly first-year ice with a thickness of 5 to 6 feet, with relatively few ridges. Ice thickness decreases gradually to 4 feet or less in Davis Strait and conditions become ice free upon reaching 64° north. From the eastern entrance of Lancaster Sound to the ice free waters, MANHATTAN II averages 8 knots and takes 105 hours, or 4.4 days. To this point, MANHATTAN II has taken 37 days for the voyage from Unimak Pass. As MANHATTAN II clears the Labrador Sea pack ice a message is received directing the vessel to Vardo, Norway on the north coast of the Scandanavian Peninsula in the southwest Barents Sea. The master contacts Ice Central for ice routing, a prediction of superstructure ice potential, and iceberg occurrence. Ice Central advises of a deep low and storm with near hurricane force winds just to the eastsoutheast of the southern tip of Greenland and although the superstructure icing potential associated with the storm is great, recommended routing will put the vessel just inside of the dispersing ice edge in the Denmark Strait, where the ice will moderate the sea, drastically reducing the amount of spray and therefore superstructure icing. MANHATTAN II increases speed to 22 knots until reaching the ice at the southern entrance to the Denmark Strait. The master is advised that should superstructure icing present any problems after passing south of Greenland to change course to the left and proceed along or just inside the ice. MANHATTAN II reaches the pack ice at the entrance to Davis Strait in 50 hours. Although some superstructure icing is encountered, it is not necessary to divert from the planned track. Furthermore, the deep low has tracked to the northeast at 35 kts and is expected to arrive in the West Spitzbergen (Svalbard) area in another 10 hours and to be considerably weakened, thereby reducing the possibility of superstructure icing when the ice pack is cleared as MANHATTAN II tracks toward Vardo. The master is advised that the east Greenland ice pack has reached the north coast of Iceland and the recommended routing will take the vessel through six to eight tenths of ice with patches of ten tenths. The ice characteristics will be predominantly winter ice but large amounts of old ice will be encountered until east of Cape Langenes, Iceland, where the amount of old ice will be markedly reduced. Ice thicknesses are expected to be about 3 to 4 feet in the first-year ice regime and 8 to 10 feet in the older ice. However, a profusion of remnant pressure ridges can be expected, together with scattered icebergs and iceberg fragments. These remnant pressure ridges should have a maximum overall thickness of up to 85 feet. Ice Central advises that MANHATTAN II should clear the ice pack after passing through 70° north at 5° west along the recommended route. From that point ice free conditions and subsiding seas can be expected to Vardo, Norway. SOA through the Denmark Strait to the ice edge averages 10 knots and takes 60 hours. Upon reaching the ice edge, sea conditions have subsided and MANHATTAN II proceeds to Vardo, Norway at 22 knots, reaching that point in 31.2 hours. From the Unimak Pass to Vardo, Norway, MANHATTAN II has taken about 43 days.

SCENARIO III: Medium Draft; Optimum ice conditions (Fig. D-2)

It is not necessary to take the medium draft vessel through the entire scenario because, winter or summer, ice conditions will be similar to those encountered by the deep draft vessel except when transiting the Canadian Archipelago. The medium draft vessel can remain slightly inshore of the deep draft vessel in both seasons. This should result in slightly better time in the summer along the north slope and perhaps better time in the winter between Cape Lisburne and Pt. Barrow. Along the north slope in the winter the medium draft vessel would most likely remain seaward of the shear zone and although encountering slightly less old ice, conditions would be similar. Therefore, Scenario III starts when the vessel, "GJOA II", departs the Tuktoyaktuk area in early September and enters ice-free Amundsen Gulf. From Ice Central, GJOA II is advised that the recommended routing will be through the lower passage to Queen Maud Gulf then east of Jenny Lind Island through Victoria Strait (West of King William Island) through Franklin Strait, Bellot Strait, Prince Regent Inlet, Lancaster Sound and then the same general routing as MANHATTAN II the previous winter.

With ice free conditions predicted to Victoria Strait, GJOA II proceeds at 22 knots until heavy fog requires the vessel to reduce speed drastically in central Coronation Gulf, where threading between islands is necsesary. To this point GJOA II has taken only 19.1 hours from Tuktoyaktuk.

Although navigation by NAVSAT (navigation satellite) is now accurate within .05 nautical miles or 100 yards, and sophisticated radar is employed, GJOA II slows to 2 knots through Coronation Gulf and Dease Strait where the fog lifts and speed is increased to 18 knots, which is held until GJOA II encounters first ice at the southern end of Victoria Strait just east of Jenny Lind Island. This is the area where the Canadian vessel Camsell had taken strike damage in the summer 1978. In reaching this point GJOA II has taken an additional 150 hours or 6.25 days. Time underway now totals 169.09 hours or 7.05 days from Tuktoyatuk.

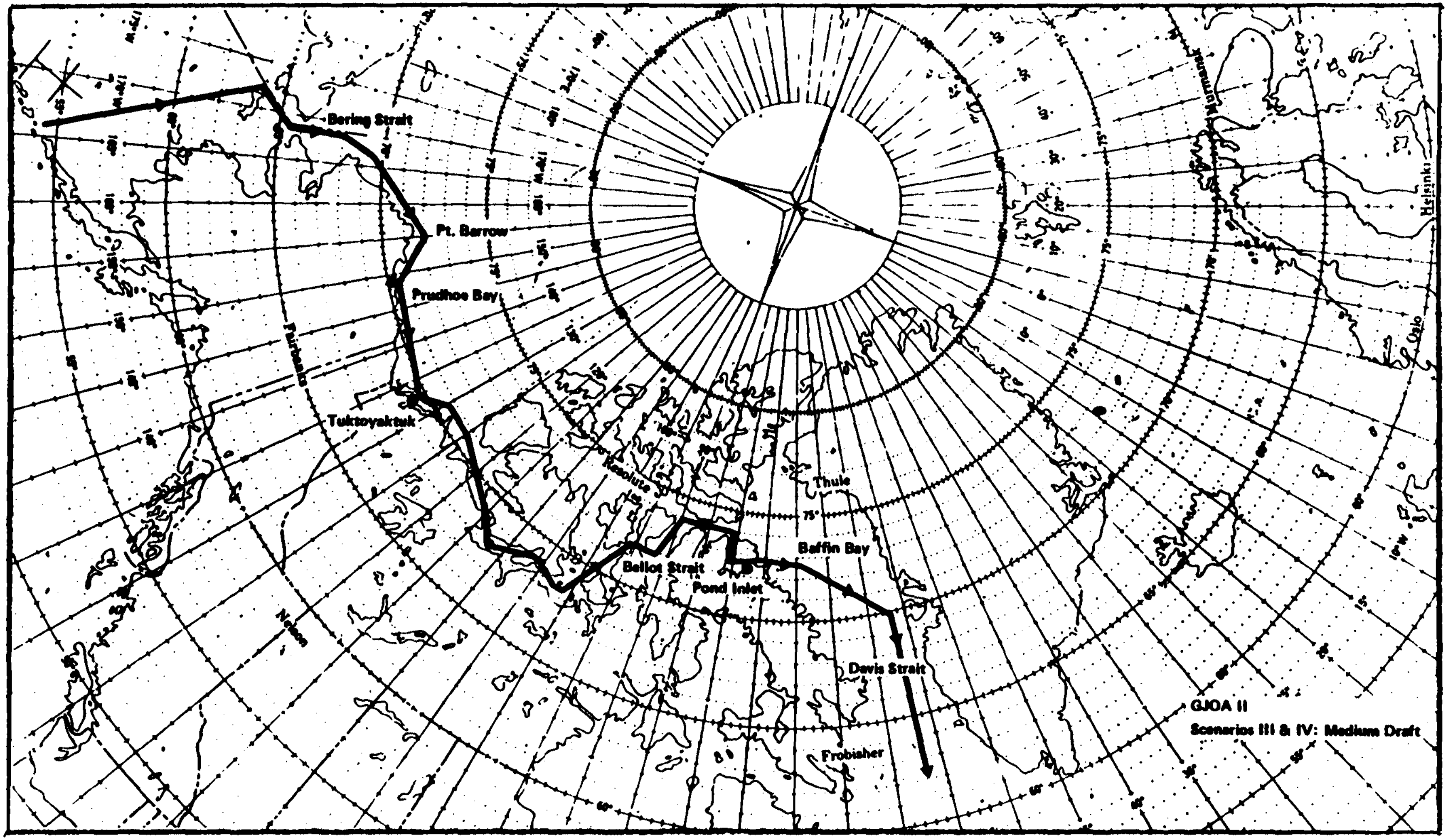

FIGURE D-2 Voyage of GJOA II

Following the recommended course on the east side of Victoria Strait and in five to seven tenths of a mixture of old and first season winter ice, GJOA II proceeds through this often treacherous Strait directly to Bellot Strait. As predicted, about midway to Bellot Strait, while in Franklin Strait, ice conditions become more favorable and eventually open water (less than two tenths of ice cover) is encountered at the west entrance to Bellot Strait. GJOA II has averaged 14 knots and taken 18.6 hours or .8 days.

Ice Central advises that Bellot Strait and the west side of Prince Regent Inlet have open water as does the remainder of the recommended routing. Peel Sound, a possible alternate route, has seven to nine tenths ice coverage remaining and the western portion of Barrow Strait has remnant ice. Therefore, the alternate is less favorable because of distance to be traveled and existing ice conditions. GJOA II proceeds through Bellot Strait, Prince Regent Inlet, and enters Lancaster Sound, averaging 20 knots and taking 9 hours or .4 days. GJOA II plans on calling at the Pond Inlet facility on northern Baffin Island where both liquid and ore cargoes are now available.

SCENARIO IV: Medium Draft; Adverse Ice Conditions (early spring) (Fig. D-2)

GJOA II, having been damaged enroute across the Beaufort Sea, calls at Tuktoyaktuk where the deck cargo of heavy equipment is swiftly offloaded. The vessel is then towed to the nearby dry dock facility where minor damage is repaired and the keel area inspected to make certain that no further damage has been sustained. GJOA II then gets underway for Pond Inlet and points south and east via the southern passage. Ice Center has advised that the Bathhurst polynya will extend deep into Amundsen Gulf but that the ice in the remainder of the passage will exceed 6.5 feet. Heavy pressure from east to west will be encountered until reaching Victoria Straits. An area of severe pressure ice at the western entrance to Coronation Gulf will impede progress. This means that GJOA II will be breaking ice under pressure for over 500 NM. With all engines on line GJOA II is able to average 4 knots through this continuous winter ice, except for the area of severe pressure at the entrance to Coronation Gulf, which slows SOA to 1.5 knots. GJOA II reaches Victoria Strait in 166.7 hours or about 7 days. The difficult portion of the transit behind, GJOA II is able to proceed at 6 knots until reaching Lancaster Sound, where the thinner ice conditions predicted are encountered and speed is increased to 10 knots to Pond Inlet. Transit toak an additional 106.7 hours or 4.5 days. The track from Tuktoyaktuk to Pond Inlet had taken about 11.5 days through locally severe conditions.

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This report addresses the maritime requirements and potential for servicing resource development in the polar areas. The basic emphasis is on the Arctic as the most important near term Antarctic marine transportation requirement for the U.S. is for a scientific research vessel. The study is concerned with the special role of maritime transportation, both inbound and outbound, and includes its ancillary facilities requirements in the movement of extractive resources of the far north. It describes the physical environment in which this transport will

20. **Abstract (continued)--**

take place and the technical considerations that the severities of the Circumpolar North impose upon maritime transportation systems. Because of the nations present energy problems and the availability of energy resources in the Arctic, an initial limited scale commercial marine transportation system for shipping crude oil from the Arctic is recommended. It is recommended that the first increment should be a single, small to medium size tanker with a corresponding local, minimal terminal facility, financially sponsored, in the beginning, by the federal government, with substantial participation and ownership by private industry. Other recommendations are also included.